M.Sc. "Exploration and Exploitation of Hydrocarbons"

Aristotle University of Thessaloniki

Master Thesis:

Environmental Impacts of Onshore Hydrocarbon Exploitation

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Summary

Hydrocarbons dominate every aspect of our lives, for more than a century, providing energy for transportation, heating, electricity, and industrial applications. Nowadays, there are more than 65,000 oil and gas fields of all sizes in the world, from which the society benefits. Fortunately, the technological advances, which call for the integration of hydrocarbons into our society, have also contributed to the modernization of the Petroleum Industry. Nevertheless, like almost any other industrial activity, the exploitation of hydrocarbons is not risk-free. In all stages of oil production - upstream, midstream, and downstream - there is a risk of accident; but, if legislations, laws and protocols are followed, the likelihood decreases significantly.

Over the past three decades, environmental awareness has grown considerably and environmental legislation has introduced strict standards to reduce failure possibility and minimize the adverse environmental impacts of oil industry's operation. To this end, the industry has to take a proactive approach and not just to comply with regulations. Integrated environmental monitoring and management plans are considered to be crucial. Yet, this is not enough. Environmental measures can and should be linked with productivity activities, from the early stages of exploration till the decommissioning of oil installations.

Although oil production takes place both onshore and offshore, this thesis focuses mainly on the onshore oil activities and discusses the potential impacts on the environment, as well as the measures needed, in order to handle and restrain those impacts. More specifically, the thesis, based on a thorough literature review, examines the environmental performance of the oil industry and analyzes the environmental impacts of onshore oil activities in different stages, e.g. from the preparation of the site up to the abandonment stage, with respect to different impacts and risks. For this purpose, the findings of previous research efforts on the risk assessment and management of environmental impacts of oil activities are used in a meta-analysis. The results show that the onshore activities are of less risky than the offshore activities. Yet, a carefully designed environmental management plan is necessary so as to reduce the overall impacts at acceptable levels and create a cleaner and safer process towards sustainability.

Contents

Table Contents

Figure Contents

Photo Contents

1. Introduction

1.1 General data

For more than a century, petroleum and natural gas (hydrocarbons) have been one of the most important energy sources. Petroleum is a liquid that consists of hydrocarbons of various molecular weights and other organic compounds. When petroleum comes straight out of the ground it is called crude oil. On the other hand, natural gas is a gas mixture consisting primarily of methane and other higher alkanes, and commonly includes small percentages of carbon dioxide, nitrogen and hydrogen sulfide. Natural gas can be associated with oil or found alone (free gas) *(Georgakopoulos, 2012).*

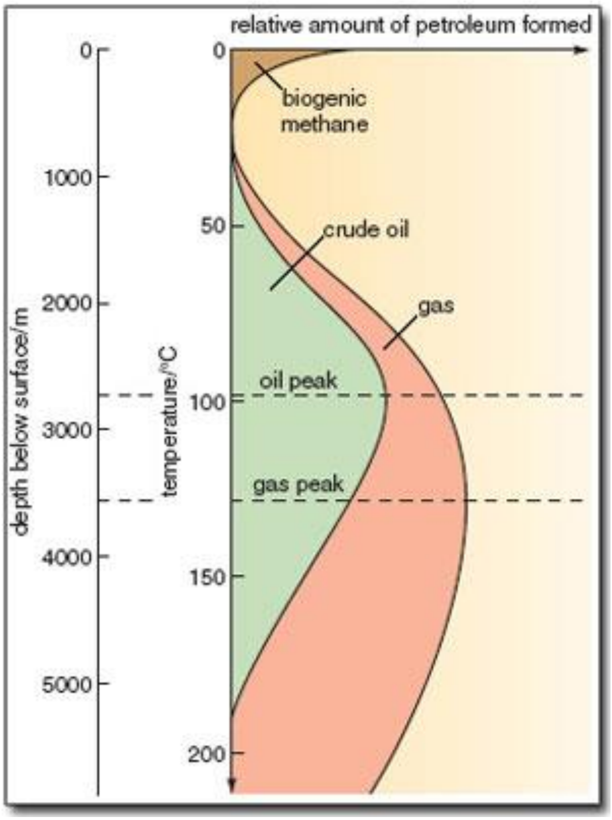


Figure 1.1.1: The relationship between depth of burial, temperature and the relative amount of crude oil and natural gas *(Source: http://www.open.edu).*

Oil and natural gas are formed from the remains of plants and animals that were deposited and buried along with sand, silt and rocks, hundreds of millions of years ago. As the rocks and silt settle layer by layer, the organic material gets buried deeper into the ground. Over time, the increasing pressure and temperature with the constant increase of depth transform the organic material to petroleum. Porosity and permeability are required in order for the hydrocarbon migration to occur from the source rock to the reservoir rock. Hydrocarbons can accumulate into the reservoir, under the right conditions and the existence of a cap rock, impermeable ceiling *(http://energy4me.org).*

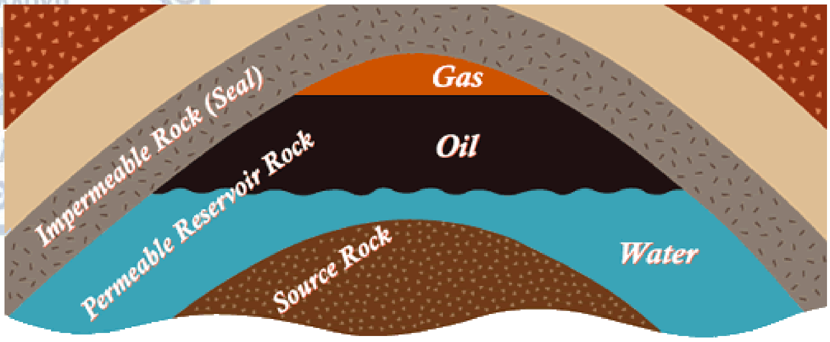


Figure 1.1.2: Illustration of the source rock and the migration to the reservoir rock. The system functions with the existence of the cap rock (impermeable rock) *(Source: Hagenimana, 2014).*

1.2 Hydrocarbon oil fields and Production

Since the early 1800s, when early explorers were looking for surface signs of potential oil existence below ground, finding oil and gas was mainly a matter of luck. Nowadays, with the new technological advance, the industry's ability to determine what lies below the ground has improved. Moreover, hydrocarbons have penetrated so deep into humans' lives that almost all power in the world depends on them. The "black gold" dominates every aspect of our lives *(*http://energy4me.org). According to image 1.2.1, Venezuela is the country with the largest oil reserves, while Russia is the country with the largest gas reserves.

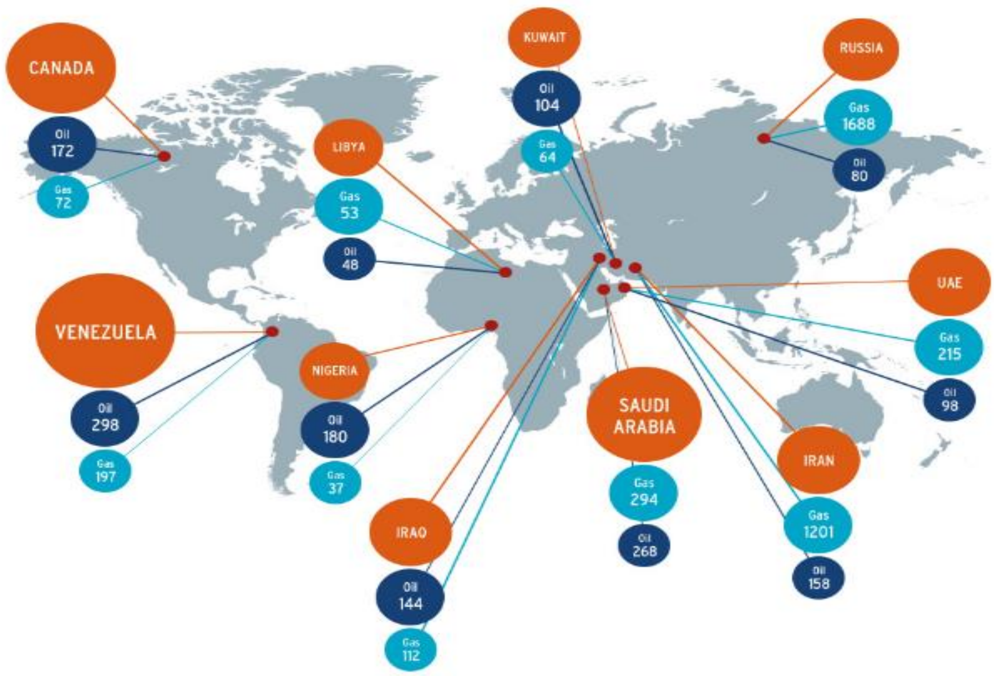


Figure 1.2.1: Oil and gas reserves, 2015. All oil numbers are in million barrels, while gas numbers are in trillion cubic feet *(Source: https://www.eia.gov/).*

There are more than 65.000 oil and gas fields of all sizes in the world and there have been over 4.000 new oil exploration licenses granted in the past 10 years. The demand for energy increases as the world population grows in numbers. Oil and gas have the lead, since they provide more than half of world's energy *(IOGP, 2018)*. Remarkable is the case of S. & Central America, where as shown in *figure 1.2.1*, the ratio of reserves/production has increased almost vertically after 2007, which in other words means that either the reserves of the country have multiplied within a decade or that the production has decreased. According to *figure 1.2.2*, which concerns the gas reserves, the ratio of Middle East seems to be reduced. That can be defined in two ways. Either the reserves have been diminished or the production has been increased.

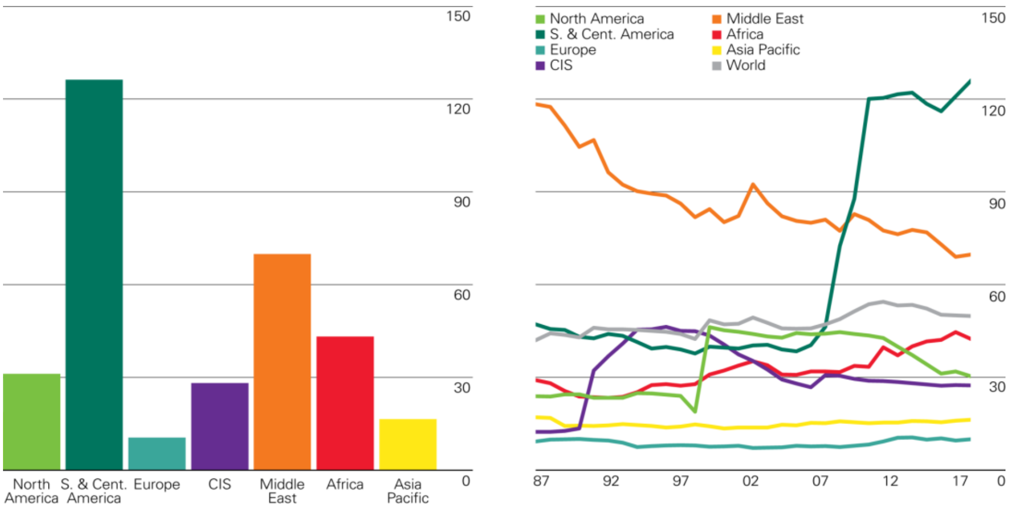


Figure 1.2.2: Ratio of oil reserves/production by region for the year 2017 (left). Historical data of oil reserves/production by region for the last 30 years (right) *(Source: BP, 2018).*

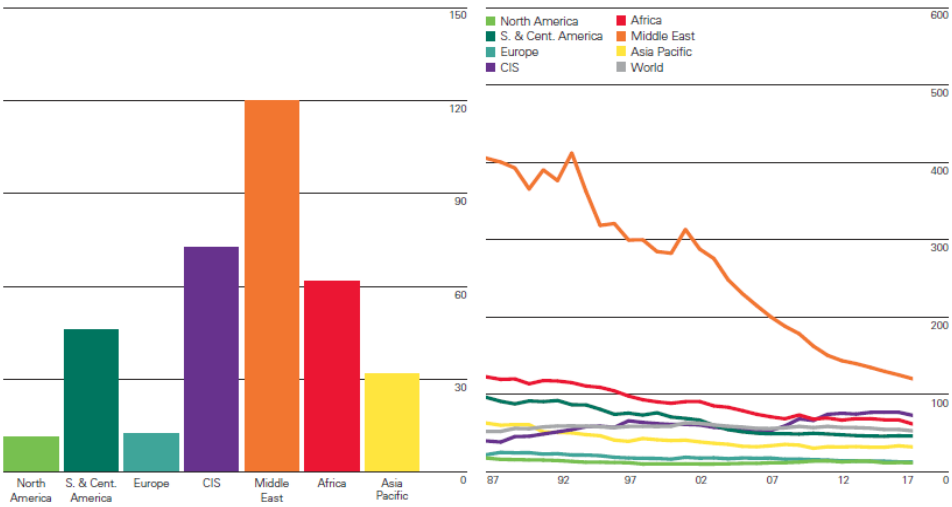
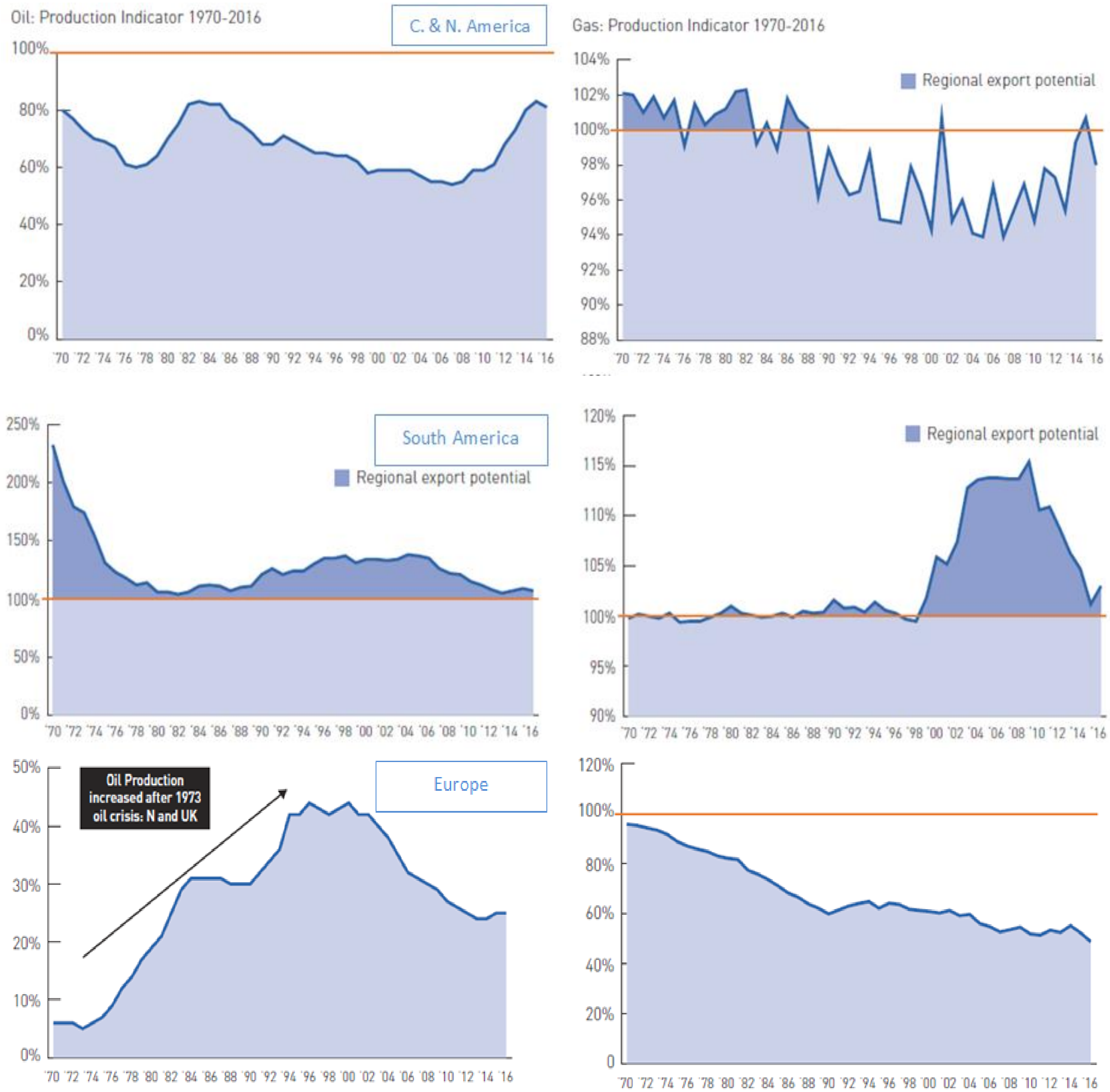


Figure 1.2.3: Ratio of gas reserves/production by region for the year 2017 (left). Historical data of gas reserves/production by region for the last 30 years (right) *(Source: BP, 2018).*

By definition, production is connected with the Production Indicator (PI), which indicates the level of a region's self-sufficiency (and export potential). For oil, is based on dividing daily production in thousands of barrels, while for gas is in billion cubic meters per year. A PI above 100% demonstrates the ability to export; while a PI below 100% shows the need to import.



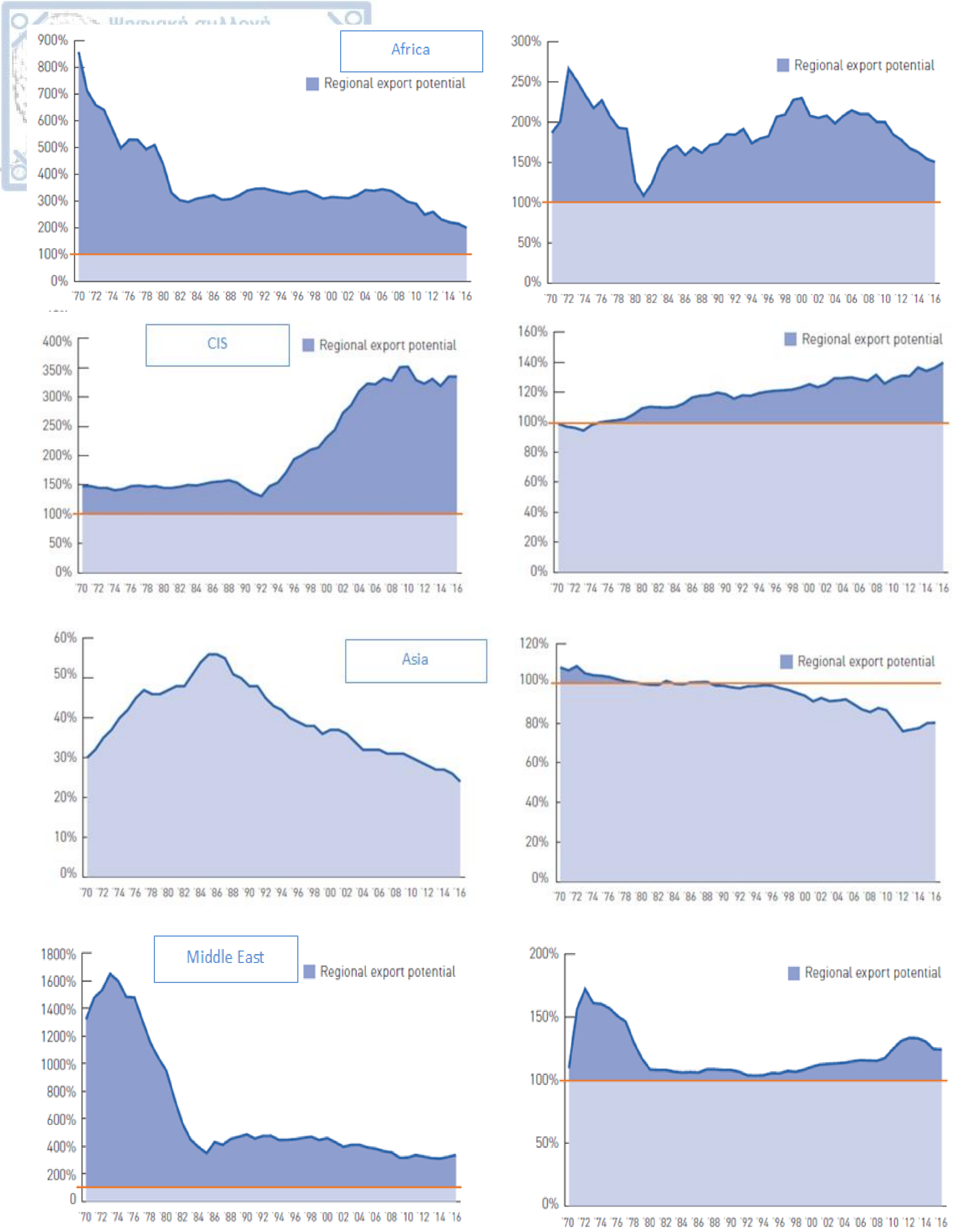


Figure 1.2.4: PI of each region based on estimations for both conventional and unconventional extraction techniques. Oil Production Indicator (left) and gas Production Indicator (right) *(Source: IOGP, 2018)*

Table 1.2.1: Production Indicator for the year 2016, in regard to every region individually *(Source: IOGP, 2018).*

Region	**Oil (%)**	**Gas (%)**
North America	81	100
South America	107	103
Asia	24	80
CIS	335	140
Europe	25	49
Africa	200	150
Middle East	337	125

According to *Table 1.2.1*, N. America, Europe and Asia don't have the ability to export oil, while Middle East, CIS and Africa have that privilege in excess. Furthermore, Europe and Asia not only don't have the ability to export gas and oil, but they need to import in order to cover their needs.

1.3 Hydrocarbon consumption

Hydrocarbons provide significant benefits to society, through the multiple uses of their products. In the United States, for the year 2016, gasoline was the most consumed oil product, with 9.3 million b/d. Second on the list is the distillate fuel oil, which includes diesel fuel and heating oil. Diesel fuel is used in the diesel engines of heavy construction equipment, while heating oil (fuel oil), is used for heating homes and buildings, for industrial heating, and for producing electricity in power plants. Total distillate fuel oil consumption in 2016 was about 3.9 mb/d. *(https://www.eia.gov).* With the extensive consumption of oil and gas, the existing oil and gas fields are depleting by about 6% per year *(IOGP, 2018).* The following figure demonstrates the relationship between production and consumption by region for the last 25 years.

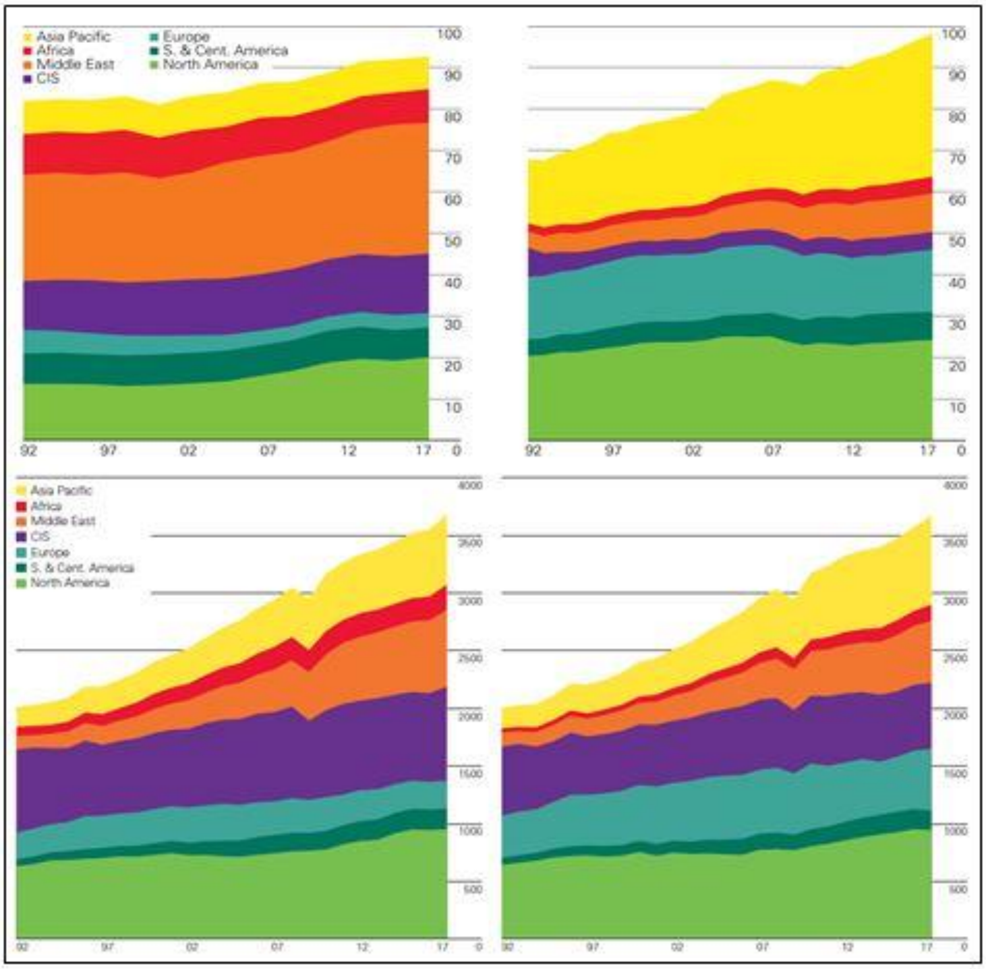


Figure 1.3.1: Oil production and consumption (up) and gas production and consumption (down), by region, in mb/d and billion m^3 respectively *(Source: BP, 2018).*

According to *Figure 1.3.1*, it can be deduced that the region with the greatest oil production is Middle East, while the region with the greatest oil consumption is N. America and Asia. On the other hand, the region with the greatest gas production is N. America, while the regions with the greatest gas consumption are N. America and CIS. Through the figures it can be noticed that Asia, during the last two decades has doubled the consumption of oil (in mb/d). The following figure *(Figure 1.3.2)* indicates the same fact but in a map form. The map displays the consumption of oil and gas by region, only for the year 2017.

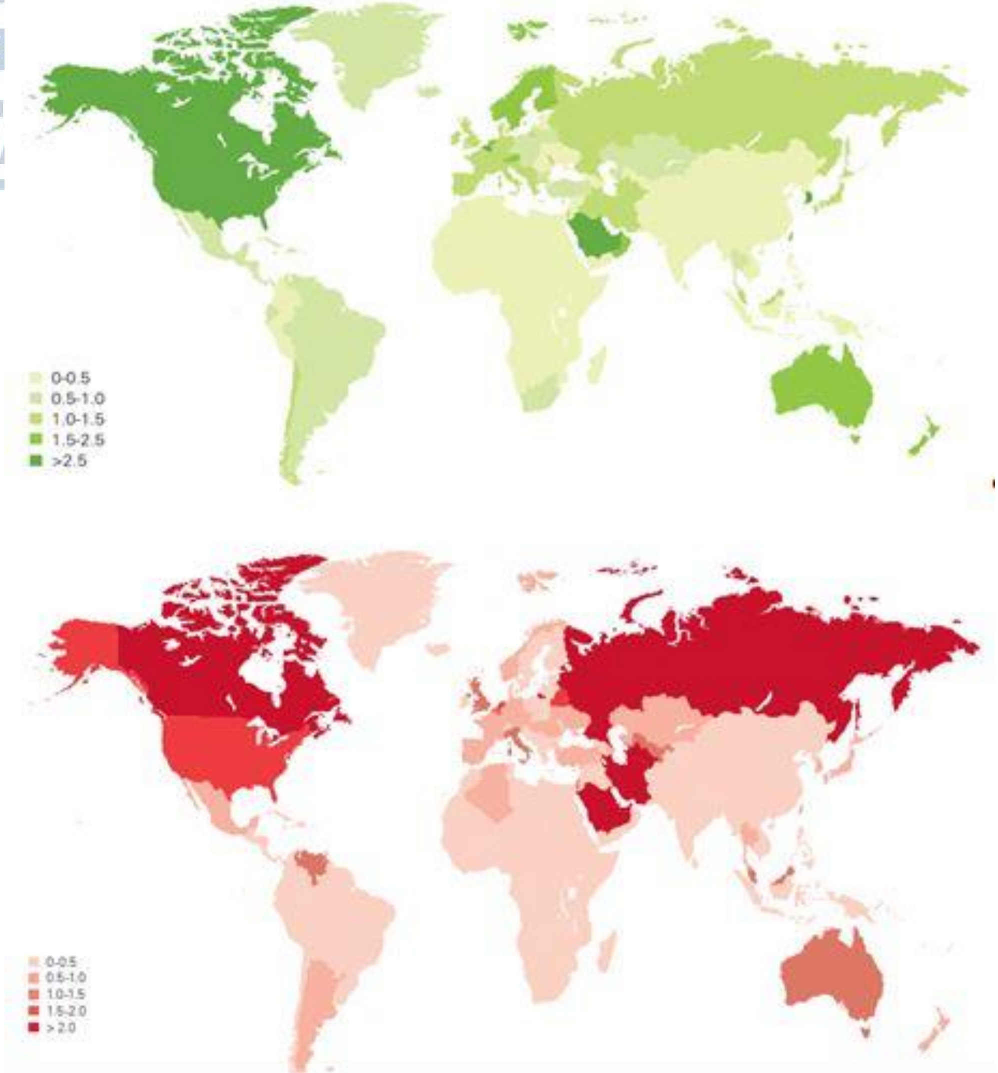


Figure 1.3.2: Global oil and gas consumption in tones and million tones oil equivalent respectively, for the year 2017 *(Source: BP, 2018).*

1.4 Prices and trade

Crude oil is one of the most actively traded commodities in the world, while the taxes coming from oil constitute a major source of income for more than 90 governments. Crude oil is also very active in stock market. For example, *Figure 1.4.1* illustrates the price fluctuation of the West Texas Intermediate (WTI) in stock market ($/b). WTI is a crude stream produced in Texas and southern Oklahoma which serves as a reference or "marker" for pricing a number of other crude streams and which is traded in the domestic spot market at Cushing, Oklahoma *(https://fred.stlouisfed.org/).*

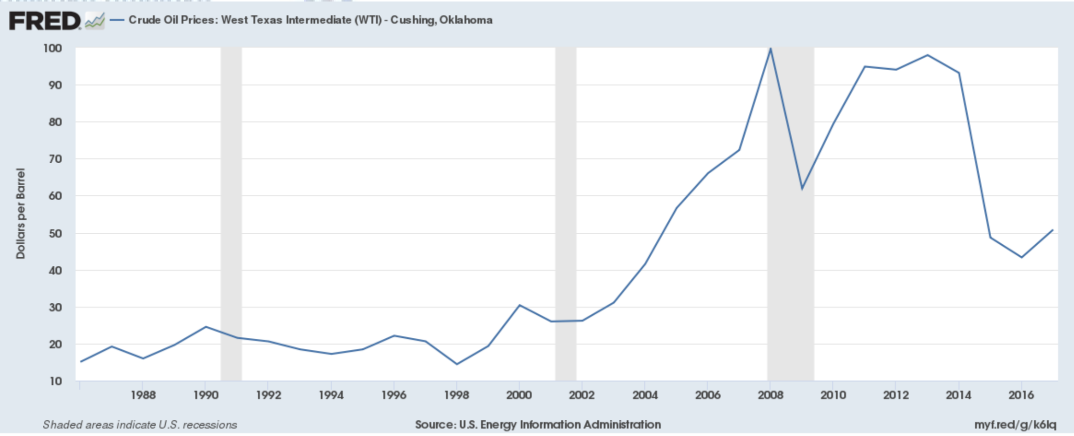


Figure 1.4.1: Price fluctuation of the West Texas Intermediate (WTI) in stock market ($/b) *(https://fred.stlouisfed.org/).*

Figure 1.4.2 demonstrates the fluctuation in oil prices since 1861. According to this figure, the price of crude oil was sky rocketed during three great events, the Pennsylvanian oil boom, the Iranian revolution and the Invasion in Iraq.

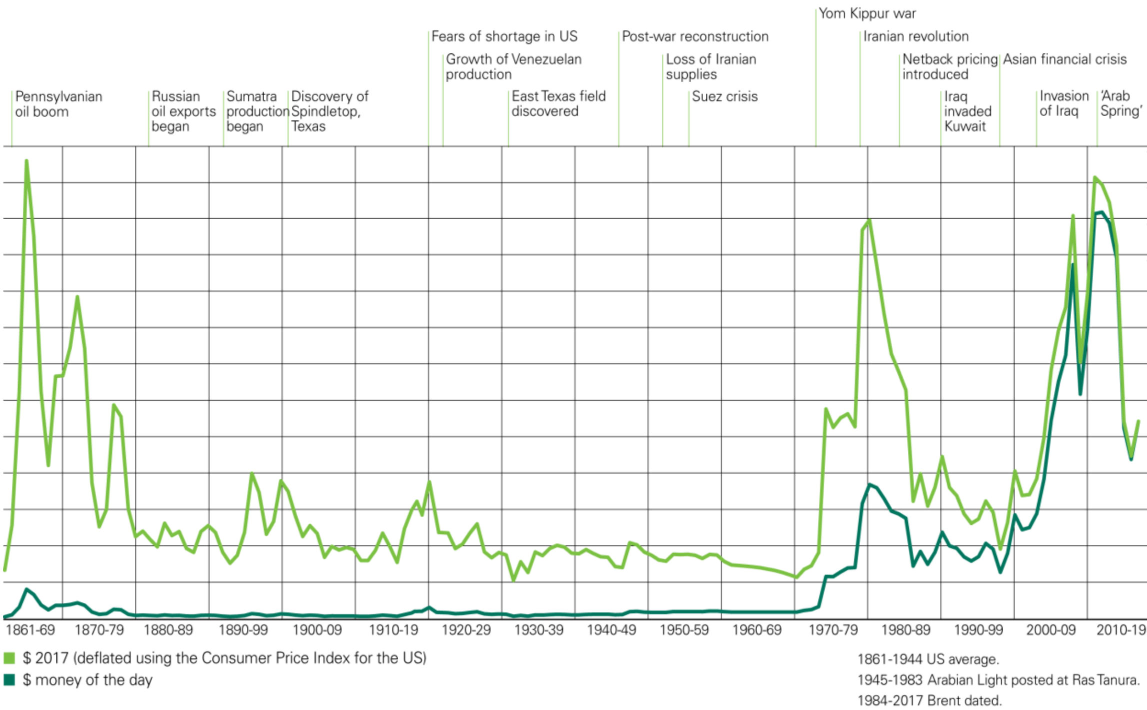


Figure 1.4.2: Global prices of crude oil ($/b) *(Source: BP, 2018).*

The following figure shows on the map the oil and gas trade movements for the year 2017. The network of oil distribution seems larger than the network of gas, with more specific and clear routes.

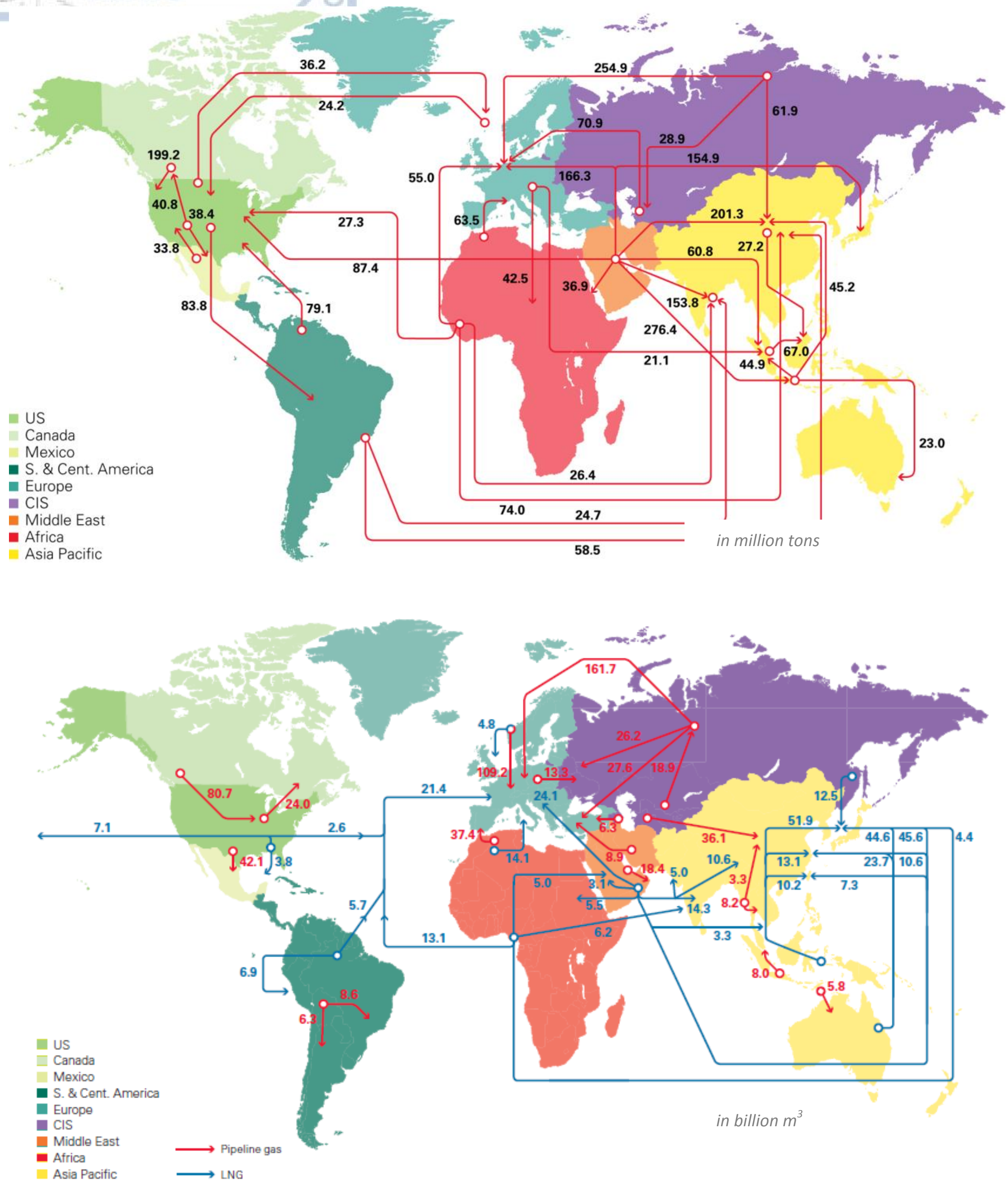


Figure 1.4.3: Global map illustrating the major oil movements of the year 2017. In general, global oil trade grew by 4.3 % in the last year, while gas trade grew by 6.2 % *(Source: BP, 2018).*

2. Oil and gas activity

2.1 General

The *Oil Industry* includes the processes of exploration, extraction, refining, transporting and marketing of petroleum products. The *American Petroleum Institute* divides the industry into five categories based on function: *(http://www.petroleum.co.uk)*

- Upstream: Exploration and development of crude oil.
- Downstream: Transport (tankers), refineries, and consumers.
- Pipeline: All hazardous pipelines (petroleum, liquid CO_2, etc.).
- Marine: Petroleum transport by water.
- Service and Supply: General category (equipment manufacturers, consulting firms, etc.).

In addition, the Oil Industry can be subdivided into two major categories: National Oil Companies (NOCs) and International Oil Companies (IOCs). IOCs' history dates back to the late 19th century. Several terms are often associated with IOCs. "Supermajor" is the most often used and it refers to the 6 largest publicly traded oil companies in the world *(http://www.petroleum.co.uk).*

Table 2.1.1: The 6 larger Oil Companies *(Source: http://www.petroleum.co.uk/).*

Name	**Location**	**Reserve Size (bb/d)**
ExxonMobil	United States	72
Royal Dutch Shell	Netherlands	20
BP/Amoco	United Kingdom	18
Total SA	France	10.5
Chevron	United States	10.5
ConocoPhillips	United States	8.3

2.2 Onshore vs. offshore activity

Through time, large deposits of oil and gas have been found, while some of them have been under production since the 1950s. Thanks to the technological advances and the new techniques discovered, the amount of recoverable hydrocarbons all around the world is constantly expanding.

The two main categories of drilling are offshore and onshore. The most obvious difference between them is the location of the drilling process. In other words, onshore drilling refers to drilling deep holes under the earth's surface whereas offshore drilling relates to drilling underneath the seabed. Onshore is considered to be the "traditional" way, since it provides natural stability due to the earth's hard surface, while extracting oil from below the surface of the ocean is considered to be more difficult *(http://www.oilscams.org)*.

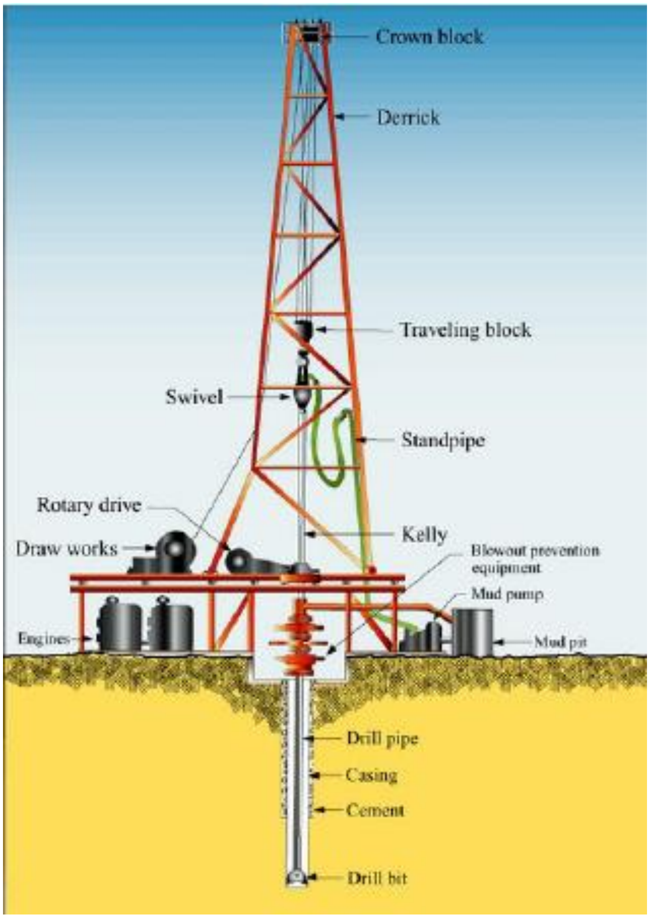


Figure 2.2.1: The form of an onshore drilling rig *(Source: https://www.researchgate.net)*.

Regarding the equipment used in both cases, offshore and onshore drilling, are not that different, since both require tools such as exploratory equipment, waste-water/oil separators, pumps, pipelines and storage tanks. Nevertheless, there are some differences according to the structure of the drilling rig. In particular, onshore drilling rigs have "classic" drilling equipment and come in different sizes and strengths. Since the ground offers a solid base, the drilling structures and storage areas are built directly on the soil. An onshore drilling rig is classified by its maximum drilling depth and mobility *(http://www.oilscams.org)*.

Onshore wells typically have a shorter lifespan, while they reach about 65% of their productivity in the first year. An onshore drilling profile can vary. Every drilling operation has to face many and different challenges, mostly related to the economics of the project. Well profiles and formations determine the drill string requirements. On average, the total capital costs of an onshore oil well range between $4.9 MM and $8.3 MM in, while additional lease operating expenses range between $1 MM and $3.5 MM *(http://www.oilscams.org).*

2.3 Stages of Onshore activity

In every drilling operation is required an enormous amount of resources, preparation, expertise and manpower. Meanwhile, a number of steps (stages) are required to prepare a location for drilling, to operate a drill site and finally to reclaim the site *(http://www.petroleum.co.uk).* There are five stages in the exploration and production 'lifecycle'. Each stage has its own risks and hazards, which need to be managed responsibly by oil and gas companies (*http://www.reportingoilandgas.org).* In particular, according to *Amec Foster Wheeler (2016)* and *http://www.reportingoilandgas.org*, these stages are the following:

- ***Exploration***

  Oil and gas exploration includes searching for hydrocarbon deposits under the Earth's surface. It consists of locating oil and gas reserves using primary technologies particularly seismic surveys and drilling wells. The exploration can be costly and risky because there might be a chance of dry wells (wells without traces of hydrocarbons). Therefore during the stage of exploration, it is often required to drill many wells in one area in order to find an oil or gas discovery, which unfortunately can be a very time-consuming process. By the end of this stage all the obtained data, such as the geology, the location and depth, the possible risk of exploitation, etc., get evaluated. When all data is obtained and the potential resources are identified by thorough investigation (more geophysical and seismic surveys), then the site is getting prepared along with the mobilization of the drilling rig and the equipment.

- ***Well design and construction***

  The main purpose of this phase is to reduce the uncertainty or possibility of losses about the size of the oil or gas field and its properties. It includes processes as, well pad construction, rig installation, drilling, and cuttings management, cementing, casing and well stabilization. A step before well completion is the well testing. This process includes: Treatment of produced water from exploratory wells, revised conceptual model and resource estimation, reiteration of exploration activities and of course an assessment of the technical and economic viability of the project. When all those processes are completed, the well is now ready for well completion and development.

➢ *Development*

This stage includes the field development with the implementation of a development plan, the well-commissioning (hook-up and production testing) and the development drilling with the production. Production in the oil and gas industry is the last phase during which hydrocarbons are extracted from an oil or gas reservoir. During production, the following processes occur:

a. Crude oil and gas processing
b. Site operations
c. Well workover
d. Process treatment systems
e. Utility systems
f. Waste Handling
g. Hydrocarbon offtakes
h. Enhanced recovery
i. Well stimulation

Production in an oil field can last several years, depending on the size of the field and how expensive it is to keep the production facilities running, in other words the profit of the procedure. Operators work in shifts to keep production going, without stopping. The development of an oil field cost hundreds of billions and lasts many years, depending on the location, size and complexity of the facilities. Onshore developments are comparatively cheaper than offshore developments.

➢ *Decommissioning and abandonment*

Decommissioning is the term used to describe the removing of the production facilities and restoring oil and gas sites that are no longer profitable. Decommissioning first requires a rehabilitation plan. The plan includes well closure and plugging, the removal of well pads and the waste management. It is important to restore the site before moving further, to the abandonment. Post-closure monitoring of the site and environmental assessment of the potential impacts are required in every case. The owners of the project are responsible for the proper execution of the plan.

3. Environmental impacts of onshore oil activities

3.1 General data

In petroleum industry, from the exploration stage to the stage of abandonment, there is a risk, the severity of which depends upon the stage of process, the size and the complexity of the project, the sensitivity of the environment and the effectiveness of planning, pollution prevention and control techniques. There are several types of potential impacts, regarding human rights, cultural and socio-economic impacts, atmospheric and biosphere impacts, as well as aquatic and terrestrial impacts. It must be noted that with proper care and attention and with correct measurements and laws, the impacts may be minimized or even avoided (*UNEP, 1997).*

For the impact assessment, first it is important to recognize the primary concerns of an oil activity, considering the scale of the impact. According to *UNEP (1997)*, the potential impacts of an oil activity are the following:

- Changes in local population level, as a result of immigration.
- Changes in local land patterns (agriculture, logging, etc.).
- Social changes, such as social structure and organization, due to new employment possibilities and income differentials.
- Changes in the availability and the access to goods and services.
- Aesthetic changes of the landscape, with new transportation systems due to the increased infrastructure.
- Problems and conflicts due to the beliefs regarding the protection of the natural resources.

Regarding the *atmospheric concerns*, the production and processing of oil releases gases to the atmosphere. Like any large-scale industrial process, there are gaseous emissions linked to energy usage that have to be accounted for. In addition, the process of bringing hydrocarbons to the surface from deep geological reservoirs, where they are held under pressure, will also result in a range of gases escaping. In particular, according to *UNEP (1997)* and *Orszulik (2016),* the emissions responsible for the atmospheric impacts are the following:

- Carbon dioxide

  Carbon Dioxide (CO_2) is a waste product of aerobic respiration and combustion of organic material and may also be released from the manufacture of materials. However, rising levels of carbon dioxide in the atmosphere are related with global warming and climate change. Recent climate changes have had widespread impacts on human and natural systems. Warming of the climate system is unequivocal, and since the 1950s. Around 132 tons of carbon dioxide are released per thousand tons of oil and gas produced. The processes of flaring, combustion and venting are the primary sources of carbon dioxide emissions.

- Methane

Methane is the simplest hydrocarbon. Its main impact is as a greenhouse gas, with 21 times greater global warming potential than carbon dioxide. Methane is emitted from process vents and gas driven pneumatic devices along with fugitive emissions and from incomplete combustion of natural gas in turbines and in flares. Methane emissions per unit of production are rising steadily, from 1.00 ton per thousand tons of hydrocarbon production in 2006 to 1.33 tons in 2012.

- Other emission gases

Other gases responsible for the atmospheric pollution are: NOx, SOx, CO and VOC. In particular, nitrogen oxides are produced whenever fossil fuels are burned. Nitrous oxides can have both local health and vegetation impacts, and may contribute to regional acid rain impacts and low-level ozone formation. Globally, nitrous oxide emissions remain stable, around 0.4 tons per thousand tons of oil produced, with higher emissions in where oil production is more energy intensive.

Additionally, Sulphur is a component of most crude oils and gases and constitutes a significant derivative of emissions. Combustion leads to the emission of Sulphur dioxide either in energy production or in flaring. Sour crude oils may also contain appreciable levels of hydrogen sulphide, with its characteristic rotten egg smell, which is poisonous and poses a significant health and safety hazard to production facilities. At moderate concentrations, hydrogen sulphide can cause respiratory and nerve damage. At high concentrations, it is instantly fatal.

Lastly, many of petroleum industry products are volatile. When exposed to air, some components of crude oil, gasoline, other fuels and many chemicals can evaporate. Hydrocarbon vapors, often described as non-methane volatile organic compounds or NMVOCs, are potentially harmful air pollutants, which can result in local health impacts as well as local or regional contributions to the formation of low level ozone; which in turn, may also impact human health (*UNEP, 1997).*

During the exploration and production oil activity, there is also a concern regarding the *aquatic environment* and its influence. During seismic operations waste volumes are minimal, whereas during production and development the volumes are increased. The most common liquid waste resulting from oil exploration and production are the following; it must be clear that the volumes of waste depend on the stage of the process (*UNEP, 1997).*

- Produced water
- Drilling fluids, cuttings and chemicals
- Process, wash and drainage water
- Sewerage, sanitary and domestic waste
- Spills and leakages

- Cooling water

The principal impact is the threat that poses regarding fresh water sources. In addition, polluted water may bring negative impacts upon the living organisms of the area and decrease the biodiversity (*UNEP, 1997).*

Due to alterations in soil conditions secondary impacts may occur, such us changes in surface and underground hydrology. Unfortunately this may end to ecological problems and changes to the local wildlife, since plants and animals can be affected by changes in their natural habitat. This kind of changes include: different breeding areas, different food and nutrient sources, as well as different migratory roots (*UNEP, 1997).*

3.2 Potential environmental impacts by stage

The data of this chapter are based mostly on a study conducted by Amec Foster Wheeler Environment & Infrastructure (2016) regarding the assessment and management of environmental impacts and risks resulting from the exploration and production of hydrocarbons.

3.2.1 "Site identification and preparation" stage

In petroleum industry, the exploration, the drilling and the extraction of oil consist the first phase, which is called "upstream phase" *(O'Rourke and Connolly, 2003).* This stage includes the election of the suitable site, through desktop studies, licensing and both aerial and geophysical surveys, as well as the preparation of the ground with the settlement of the heavy equipment. In every case, certain management measures are developed in accordance with the E.U legislation that aim in the prevention and minimization of the impacts *(Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

Aerial surveys are conducted by low flying aircrafts whose engines will generate noise and emissions similar to those emitted from fossil fuel combustion engines on the ground. The impacts of this stage are the gas emissions that contribute to the climate change and the noise from the aircraft engine. Regarding the **geophysical-seismic survey**, which is necessary in order to define the geology of the area, a source is needed to create vibrations (sound waves) into the ground *(ibid).* As a result; noise and vibration are the two primary impacts of the process. Noise, is a physical disturbance that depending on its level of sound and duration, can cause various impacts on living organisms. The long-term exposure of the animal populations to these factors, may cause serious problems regarding their migratory roots and theirs undisturbed existence *(https://www.slideshare.net)*. In case of an improper or insufficient surveying, a contaminated material is released from seismic machines or vehicle engines that can lead to surface and underground water contamination. In addition, due to vibrations during the survey a large quantity of dust is released. From those vibrations, local infrastructure and archaeological sites may be affected, as well as the fauna and flora of the area *(ibid)*. The following figure illustrates the source of noise and vibration, perceivable by the living organisms of the areas near the rig.

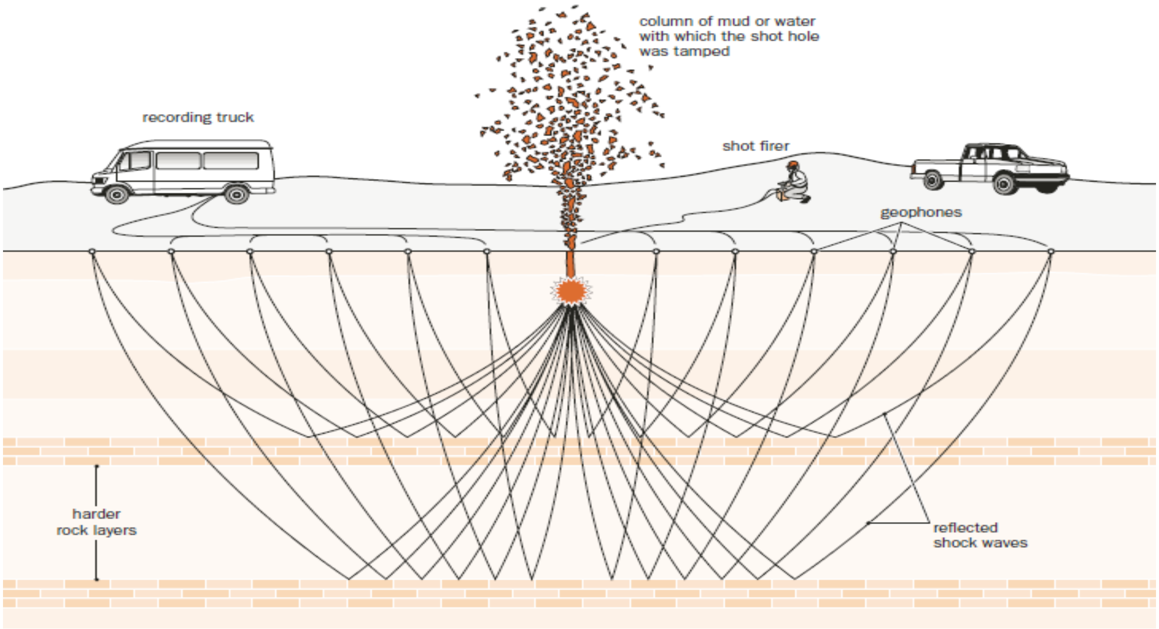


Figure 3.2.1.1: Geophysical surveys in the imminent area at the stage of exploration *(Source: UNEP, 1997).*

To this point, it the potential geomorphologic damage by the creation and maintenance of access routes in the entire project area (**mobilization**) must also be included. This will cause the exposure of deeper layers of the ground to the atmosphere, leading to deforestation and erosion, as well as to industrial traffic due to road construction. Other environmental hazards are related to surface water (contamination from surface runoff) and releases to air. In particular, emissions from vehicles can degrade local air quality and assist to the deterioration of the greenhouse effect. However, the risk regarding the environment during the phase of seismic activity and mobilization is considered to be reasonably low.

Once all the permits are obtained, the site is cleared for **site preparation**. At this process, the percentage of a potential runoff is getting higher than it was earlier. The impact in case of a release of contaminative material from engines is getting also higher as well as the dust emissions. Along with fuel related emissions that have the potential to affect local air quality; the emissions of greenhouse gases will also have a contribution towards climate change. To conclude, the environmental footprint during this process is considered larger than the other processes mentioned above *(Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

Table 3.2.1.1: Synopsis of the potential impacts during the first stage of onshore activity (Source: *Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

Process	Impact
Identification of the area and licensing	Desk job: No specific impacts
General investigation of the area (satellite, aerial survey)	Local air quality
	Contribution to global warming
	Noise
More specific investigation (geophysical/seismic survey)	Water contamination
	Local air quality
	Contribution to global warming
	Noise
	Vibration and tremor
	Biodiversity
	Visual impact
	Traffic
Model development and environment/social survey	Desk job: No specific impacts
Mobilization and equipment establishment	Water contamination
	Local air quality
	Contribution to global warming
	Noise
	Traffic
Site preparation (site clearing and accessibility)	Water contamination
	Local air quality
	Contribution to global warming
	Noise
	Biodiversity
	Visual impact
	Traffic
	Land take

3.2.2 "Well construction and completion" stage

Once the site is ready the next step is to proceed to well design and completion. At first, wildcat well drilling is installed, in order to obtain more information according to the underground geology, and then when data is gathered, the resource appraisal well is eventually carried out. Once the decision is made to turn a drilled well into a producing well, well completion is required. The well completion involves case installation, cementing, perforating, and lastly production *(Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

Contamination and soils compacted on construction site can generate surface runoff if not appropriately managed, while a low level lighting at night cause the disturbance of the fauna. During exploration drilling, there may be an increase in gas emissions (particulates, oxides of nitrogen, carbon monoxide, Sulphur dioxide and volatile organic compounds (VOCs)), due to heavy machinery used, which could contribute to the climate change. With the appropriate risk management, the environmental hazards of well pad construction could be relatively low (*Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016*).

Regarding the local communities, the threat to the survival of various indigenous populations must be highlighted. Territorial integrity is necessary for the cultural evolution. The most distinctive example is the indigenous people of Amazon. Throughout the Amazon basin, road building causes deforestation, which contributes to loss of territory and displacement of native groups. The opening of access roads leaves open the passage to the communities and threatens with the colonization of those areas. This colonization can also bring infectious diseases to previously unexposed native populations; while at the same time, the lack of agreement amongst people of different communities and different ethnicities can lead to conflicts over the dominance of oil resources. It is pertinent to note that social crises and restiveness in these areas are a result of land ownership, resource ownership and mineral right ownership structures *(O'Rourke and Connolly, 2003).*

Further on, after the set-up of the well pad, the **installation of the drilling rig** follows. Compared to well pad construction, the rig installation causes fewer environmental hazards. The potential impacts of the process are releases to air, noise and traffic. Once the rig is ready, **well drilling** takes place. In both vertical and deviated wells, the use of large and heavy machinery is required. The produced water of the drilling process may be contaminated with drilling fluids, which later on will contaminate the soil and the surface water. Moreover a potential leakage or discharge of drainage water may result in pollution of the underground water *(UNEP, 1997)*. Also an increase in heavy truck traffic would accelerate the deterioration of roads, as well as the potential for an accident within the project area. To conclude, during the phase of drilling there is a chance of occurring incidents such as rig explosions and well blowout. This kind of incident causes an immediate adverse effect on the environment and on the entire surrounded area *(Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

The drilling process also generates **mud cuttings** which may be contaminated with drilling fluids (oil based mud or NADF) *(Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).* The water that cycle during drilling can be radioactive, since it can be contaminated by the chemicals they use during extraction. The fluids with their additives accumulate in large quantities, and at the end they are disposed in waste pits. Exposed waste pits pose a danger not only to aquifers but also to animals and birds that mistake the pits for water holes and become coated with toxic wastes. A potential chronic exposure of animal populations may lead to their extinction *(O'Rourke and Connolly, 2003).* With adequate risk management measures, such as a comprehensive waste management plan, the environmental hazards will be relatively low.

In every case, the safety and the stability of the well must be asserted. This assertion is accomplished by the installation of **casings and their cementing**. Inadequate casing and cementing may lead to drilling fluid, chemicals or hydrocarbon seepage and leakage into groundwater or surface water bodies. Improper casing installation can also compromise pressure control in the well, which in extreme cases can lead to a catastrophic blowout and the loss of the well. In general the impacts to the atmosphere, soil and water are the same as previous, but with a greater percentage of risk and consequence *(Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

Once the well reaches the formation which carries the hydrocarbons, the well gets plugged. By this movement the safety and **stability of the well** is ensured. Lastly, a **well control** is required in order to verify once more the safety of the well and to be able to proceed to **well completion**. After that perforation takes place. Perforation is a special operation to create an efficient communication path between a wellbore and a reservoir by creating tunnels *(Stamataki, 2017).*

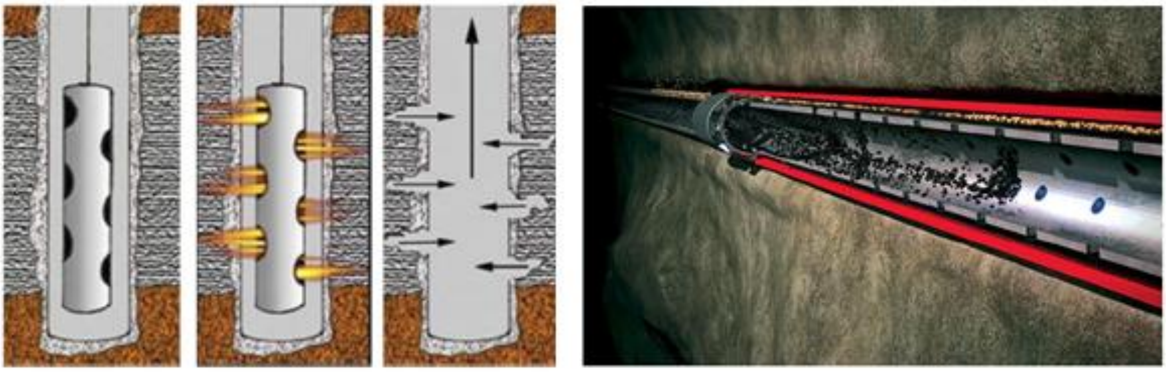


Figure 3.2.2.1: Well completion with the method of perforation, a drilling technique for the oil extraction *(Source: Stamataki, 2017).*

Table 3.2.2.1: Synopsis of the potential impacts during the second stage of onshore activity *(Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

Process	Impact
Well pad construction	Groundwater contamination
	Surface water contamination
	Local air quality
	Contribution to global warming
	Biodiversity
	Visual impact
	Noise
	Traffic
Rig installation	Local air quality
	Contribution to global warming
	Noise
	Traffic
Drilling of vertical or deviated wells	Groundwater contamination
	Surface water contamination
	Water resource depletion
	Local air quality
	Contribution to global warming
	Biodiversity
	Noise
	Traffic
	Groundwater contamination (major accidental spills)
	Surface water contamination (major accidental spills)
	Local air quality and global warming (major accidental spills)
	Biodiversity (major accidental spills)
	Groundwater contamination (minor accidental spills)
	Surface water contamination (minor accidental spills)
	Local air quality and global warming (minor accidental spills)
	Biodiversity (minor accidental spills)
Drill cuttings management	Groundwater contamination
	Surface water contamination
	Local air quality
	Contribution to global warming
	Traffic
Casing and cementing	Groundwater contamination
	Surface water contamination
	Local air quality
	Contribution to global warming
	Water resource depletion
Well Stabilization	Groundwater contamination
	Surface water contamination
	Local air quality
	Contribution to global warming
Well testing	Local air quality

	Contribution to global warming
Management of produced water from exploratory wells	Groundwater contamination
	Surface water contamination
	Local air quality
	Contribution to global warming
	Biodiversity
	Noise
	Traffic
Well completion	Groundwater contamination
	Surface water contamination
	Local air quality
	Contribution to global warming
	Noise

3.2.3 "Development and production" stage

Once casing, cementing and perforation have taken place, and the appraisal is ready for production, a **development plan** needs to be defined. It is important to estimate the potential environmental impacts in the first place. The process and technologies required range from case to case *(Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

In this stage the possibility of an impact to happen increases, and so does its severity. The long term loss of habitat and the use of land, the permanent facilities that require increased footprint (landtake), the long-term effects of vegetation clearance, the erosion and the changes in surface hydrology, the large scale of construction activities, the noise and vibrations, as well as the emissions and the aesthetic/visual intrusion, are considered crucial and demand an effective management plan *(UNEP, 1997).*

In general, the impacts are more or less the same at each stage. What causes the alarm is the magnitude of the impact. In order to start production, the well needs to be submitted under various tests, mostly chemical testing (hydrostatic test) and commission (pressure testing, control testing, etc.), which have the greatest potential for impacts. During the phase of **pre-commissioning**, there is a significant potential to contaminate groundwater by hazardous chemicals. In case of mistreatment or spillage accident, there will be a surface runoff of harmful chemicals, as well as erosion and sedimentation at discharge point of testing liquids. The water that is required for the hydrostatic testing needs to be in small quantities, because a toxic chemical spill from the testing can lead to permanent loss of habitat, and then the effectiveness of the treatment will be challenging *(Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

Moving forward, the **development drilling** takes place, whose scale will be determined by the agreed development field plan. Further well drilling or enhancements for oil or gas production may be required on a large field. The environmental hazards and impacts are similar to those stipulated under drilling; however there may be cumulative impacts due to the increased scale of the operations *(ibid).*

During the phase of production, large quantities of carbon dioxide are emitted. Other releases to air include methane arising from process vents and potentially from leaks, flaring and combustion *(UNEP, 1997).*

Photo 3.2.3.1: Oil combustion *(Source: https://www.offshore-mag.com/).*

Numerous environmental issues are caused by the combustion of petroleum and its products, such as air pollution, water pollution and global warming. Particularly, the combustion of oil results in six primary air pollutants: VOCs, oxides of nitrogen (which combine with VOCs to produce low-level ozone), carbon monoxide, oxides of sulfur, and lead. Gas flaring, which is the controlled disposal of surplus (unwanted) combustible natural gas, may also cause problems. Through this process is produced noise, toxic gases, soot, excessive heat and radiant energy are produced, as well as CO_2 emissions that cause global warming, and methane that causes ozone depletion *(O'Rourke and Connolly, 2003).* The combustion of oil is also responsible for the formation of acid rain. The increased concentrations of nitrates and other acidic substances have significant effects on the pH levels of rainfall. Data samples that were analyzed from the United States and Europe from the past 100 years showed an increase in nitrous oxide emissions from combustion *(https://www.epa.gov/).* The risk levels are considered generally high in this phase *(Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

In case of a mistreatment during the ascent of the hydrocarbons, a well workover is considered to be indispensable in order for the problem to be solved. Well workovers or interventions, are performed by inserting tools into wellbores to conduct maintenance, testing or remedial actions. The main environmental impacts would potentially be to surface waters where any chemical spillages or leakages may contaminate surface water bodies via surface runoff (ibid).

Also, the majority of oil and gas wells produce a **proportion of water** alongside hydrocarbons. This proportion tends to increase over the lifetime of the well. Similar to drilling for exploratory wells, produced water may be produced in development wells and during the production process of the development well. Water generation becomes a major waste management concern over the long-term operation of oil or gas field because water production typically increases with the age of the production well. Typical watercuts (proportion of produced water to oil) range from 25% or lower at the start of production (1 barrel of water produced per 3 barrels of oil) to 75% or higher later in production (3 barrels of water produced per 1 barrel of oil) *(http://documents.worldbank.org).* With proper risk management measures in place, the environmental risk is considered to be low, regarding surface water, air and noise impacts, whereas groundwater contamination is more difficult to be confined *(Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

Lastly, **utility systems** are required as part of production phase for management of sludge. The impacts regarding water and soil are the same as above. Waste from the utility system will require further treatment and disposal offsite. **Waste handling** on site, is required as part of the production phase. The potential impacts are associated with transportation of waste for treatment and disposal. The quantity of waste transported varies greatly depending on site-specific factors. Proper risk management keeps the environmental risk in low levels *(ibid).*

After all of those processes, the product that arrives on the surface is a mixture of hydrocarbons (oil), dissolved gas and produced water or mainly gas and produced water in gas fields. This mixture needs to be distinguished and every phase must be separated from the others. For this purpose the mixture is sent offsite for refining (**Hydrocarbon offtakes**). Refining consists one of the most basics operations in the oil industry. Oil, as crude oil, has limited uses. It must be separated, converted, and refined into useful products such as gasoline, heating oil, jet fuel, and petrochemical feedstock. The basic oil refining process involves thermal "cracking" which applies both pressure and intense heat to crude oil in order to physically break large molecules into smaller ones. At the end of this process, the crude oil's components that were not converted into useful products are released to the environment *(https://www.environmentalpollutioncenters.org).*

Photo 3.2.3.2: Oil refineries in Attica, Greece *(Source: http://www.activegreece.gr/).*

The process of refining produces huge volumes of air, water, and solid waste, including toxic substances such as benzene, heavy metals, hydrogen sulfide, acid gases, mercury, and dioxin. All petroleum derived products may cause adverse impacts on the ecosystem. Ecosystem food chains can be affected and biodiversity can be decreased. Also, thermal pollution from the release of wastes also can disrupt ecosystems. There have been conducted several independent studies on the refinery emissions in the United States of America. In particular, multiple analysis of data, reveals that the petroleum refining industry releases 75% of its toxic emissions to the air, 24% to the water (including 20% to underground injection and 4% to surface waters), and 1% to the land. Taking into account the emissions of carbon dioxide, an increase in the amount of carbon dioxide results in an increase in surface temperatures (greenhouse effect) *(O'Rourke and Connolly, 2003).*

It must be noted that during all site operations associated with oil and gas exploration and production there is a risk of accidental spillages of chemicals, hydrocarbons, drilling mud or cement. The likelihood of accidental spillages may increase when the site is situated in extreme climates, has more severe process conditions such as higher temperatures and pressures, larger and more complex facilities, inhospitable regimes and greater financial and resource challenges as competition increases *(Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

The incident most probable to occur during the phase of transportation before and after the refining process is the oil leakage and spillage. The oil spills that occur onshore may be divided into two groups. In case of a surface oil spill, the contaminated area is easy to be identified by visible traces such as oil stains and odors due to the vapors emitted by the spilled oil. On the other hand, underground oil spills are more difficult to catch and yet may be more problematic, if they reach underground water and travel with it *(https://www.environmentalpollutioncenters.org).*

Photo 3.2.3.3: Transportation of oil by pipelines. On the left is the Trans-Alaska Pipeline System (TAPS), while the photo on the right is from the IP project in Iran-Pakistan *(Sources: http://www.energytrendsinsider.com/ and https://tribune.com.pk/ respectively).*

Both surface and underground oil spills have the potential to contaminate soil, sediment, water (underground and surface), and air (due to many volatile compounds emitted by the spilled oil). In general, the scale of the damage depends on the kind of oil, the size and the season of the spill, and the vulnerability of the ecosystem. In every case what will aggravate the situation is the existence of bad weather conditions. Spillages can lead to negative economic impacts due to pollution and to aesthetic issues that affect the residents in multiple ways. Negative economic impacts, such as the reduction of tourism and the property value reduction, affect the community where the oil spill occurred *(https://www.environmentalpollutioncenters.org).*

Due to the necessity to transfer oil, new developments have been made, allowing oil to be transferred though complex and peculiar routes, almost to any place on this world. Some of the major oil routes stretch from Middle East to Japan, from South America to Europe, and from Africa to United States. Regarding the transport of oil by pipelines, onshore pipelines are generally one of three types: Those that are built within the oil and gas fields for the collection of oil (infield lines), those that are built to cover longer distances between the point of production and consumption (cross-country pipelines), and those with smaller diameter, low-pressure pipelines used for distribution and supply (usually natural gas) *(Orszulik, 2016).*

Photo 3.2.3.4: Transport of oil by trucks (left) and trains (right) *(Sources: http://www.farmersoilcoinc.com/ and https://oilprice.com/).*

Regarding the potential effects of oil spills on humans, they can be classified to direct and indirect, depending on the way of contact. In particular, direct exposure occurs close to where people live or work by breathing the contaminated air, while the indirect exposure occurs when people live in places far from where the actual oil spill took place, by swimming into contaminated water, or by eating contaminated food. Some oil compounds have the ability to accumulate in living organisms and rise in number along the food chain *(https://www.environmental pollutioncenters.org).*

To conclude, the types of oil that constitute the greatest threats are gasoline and diesel fuel, whose molecules are smaller. Because of their size, gasoline and diesel spills evaporate more quickly. Crude oil and other heavy oils may also be dangerous, although they are less toxic, thick and gluey, because of the fact that they have a very slow rate of evaporation, so they can remain in the environment for a larger period of time (*https://www.epa.gov/).*

During the late stages of well production, **water flooding** is considered essential, since by injecting water into the well, the water displaces trapped oil and boosts the production. The quantity of water stored, treated, pressurized and injected depends on site-specific factors such as the size of the reservoir and the water resource available. In addition, water injection is often an ongoing process, which is repeated until the water cut of the produced oil is so high (90-99%) that the well is no longer economically viable. The potential impacts of this process are the emissions of SO_2, CO_2, NOx, the noise and dust from the equipment and vehicles, as well as the depletion resulting from the high water demand. The increased land take resulting from the need to store water, the visual impact due to physical presence of water storage, the injection equipment and the increased traffic required to transport equipment and materials for the injection, are also considered as probable impacts of the process *(Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

Ultimately, during **enhanced recovery**, the injection of steam, polymers, CO_2 or hydrocarbon gas into the well is performed to boost the production. This process may cause problems such as chemicals penetrating subsurface groundwater, surface runoff, gas emissions, and others that were mentioned previously above. Low volumes of water, together with a proppant such as sand and other chemicals including thickening agents and surfactants, are injected into the well to fracture the formation containing the hydrocarbons (**well stimulation**). Associated environmental hazards arise from the need to supply and store large quantities of liquid and chemicals at the site, such as fracturing fluids penetrating subsurface groundwater, seismicity induced by the force of the subterranean fracturing process, surface or storm water runoff and emissions of SO_2, CO_2, NOx and dust. Moreover, the depletion resulting from the high water demand of fracturing operations, the increased land take, the noise resulting from equipment used to pressure and inject the fracturing fluid, and lastly the visual impact and the traffic *(ibid).*

Table 3.2.3.1: Synopsis of the potential impacts during the third stage of onshore activity (Source: *Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

Process	**Impact**
Field development concept	Desk job: No specific impacts
Construction and installation (Implementation of development plan)	Surface water contamination
	Local air quality
	Contribution to global warming
	Land take
	Biodiversity
	Visual impact
	Noise
	Traffic
Well commissioning	Groundwater contamination
	Surface water contamination
	Local air quality
	Contribution to global warming
	Water resource depletion
	Biodiversity
	Noise
Development drilling	Groundwater contamination
	Surface water contamination
	Local air quality
	Contribution to global warming
	Water resource depletion
	Land take
	Biodiversity
	Noise
	Visual impact
	Traffic
Site operations (Major accidental spillages)	Groundwater contamination
	Surface water contamination
	Releases to air
	Biodiversity
Site operations (Minor accidental spillages)	Groundwater contamination
	Surface water contamination
	Releases to air
	Biodiversity
Well workover	Surface water contamination
Process treatment systems (produced water)	Groundwater contamination
	Surface water contamination
	Local air quality
	Contribution to global warming
	Noise
Utility systems (Wastewater and sewage)	Groundwater contamination
	Surface water contamination
	Local air quality
	Contribution to global warming

	Noise
	Traffic
Waste handling	Groundwater contamination
	Surface water contamination
	Local air quality
	Contribution to global warming
	Noise
	Traffic
Hydrocarbon offtakes	Surface water contamination
	Local air quality
	Contribution to global warming
	Noise
	Traffic
Hydrocarbon production and processing	Groundwater contamination
	Surface water contamination
	Local air quality
	Contribution to global warming
	Noise
	Traffic
Enhanced recovery (water flooding)	Local air quality
	Contribution to global warming
	Water resource depletion
	Land take
	Noise
	Visual impact
	Seismicity
	Traffic
Enhanced recovery (substance injection)	Groundwater contamination
	Surface water contamination
	Local air quality
	Contribution to global warming
	Water resource depletion
	Land take
	Noise
	Visual impact
	Seismicity
	Traffic
Well stimulation (hydraulic fracturing)	Groundwater contamination
	Surface water contamination
	Local air quality
	Contribution to global warming
	Water resource depletion
	Land take
	Noise
	Visual impact
	Seismicity
	Traffic

3.2.4 *"Well closure and Decommissioning" stage*

When the life of the well expires then **decommissioning** takes place, including the plugging of the well, the removal of the well pad and the waste management. All actions must be properly done for the effectiveness of the sealing. Similar to site preparation in exploration or field development for production, increased numbers of vehicles, plant and machinery will be used for dismantling and removal activities. These activities would generate waste and increase the frequency of emissions to air and the noise for the duration of the decommissioning activities. In addition, improper control may cause accidents and spillages, erosion and changes in surface hydrology that will ultimately result in soil and water contamination *(UNEP, 1997).* Any spillages and leakages onto the ground could result in long-term impact. It must be noted that it may not be possible to return the entire site to its primary form, and that some parts of the equipment may never be able to be removed. Land take and visual impact are considered as part of environmental hazards due to the equipment potentially remaining on site permanently, but the risk remains low in view of the small scale of the equipment *(Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

After the removal of the equipment, **site restoration** takes the lead. Processes required to restore the site include stabilizing areas and slopes, breaking-up compacted surfaces, re-vegetation, replacement of topsoil, and seeding new vegetation. Noise and traffic issues from transporting the required plant and equipment are the main environmental aspects for this activity. Despite the gas emissions and the dust, this process is characterized by a relatively low risk level, since site restoration activity is expected to be short and transient and on a much lower scale than those observed during site exploration and production *(Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

Table 3.2.4.1: Synopsis of the potential impacts during the fourth stage of onshore activity (Source: *Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016,* own editing).

Process	Impact
Process planning	Desk job: No specific impacts
Decommissioning (plugging of the well, equipment removal)	Groundwater contamination
	Surface water contamination
	Local air quality
	Contribution to global warming
	Land take
	Visual impact
	Biodiversity
	Noise
	Traffic
Rehabilitation (site restoration)	Noise
	Traffic
	Local air quality
	Contribution to global warming

3.2.5 *"Post closure and Abandonment" stage*

Lastly, the owner of the well is responsible for its proper closure and **abandonment**. The well may be closed improperly to save costs, which increases risks of long-term integrity failure. Orphan wells impose significant costs on competent authorities, who must fund proper abandonments and even clean-ups if the owner cannot pay. A crucial point is to be able to maintain the integrity of the well for as much as possible, which can be succeeded with the contribution of the **monitoring process** via the Environmental Impact Assessment. The **well integrity** refers to the possibility over time, of some hydrocarbons to leak from the well bore. This can lead to the pollution of surface and ground water and also to the amplification of the greenhouse effect. It is possible that the lack of monitoring can lead to well integrity failure *(Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

Table 3.2.5.1: Synopsis of the potential impacts during the fifth stage of onshore activity (Source: *Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016*, own editing).

Post closure & Abandonment (monitoring and well integrity)	Groundwater contamination
	Surface water contamination
	Local air quality
	Contribution to global warming

3.3 Environmental performance of oil activities

Hereinafter, information about several environmental indicators, regarding the performance of the oil industry, is presented. These indicators are: gas emissions, energy consumption, flaring and the water discharges, as well as spillages and leakages of oil and its products. In particular, according to *IOGP (2017)*, the results are the following:

- *<u>Gas releases</u>*

Releases of gases to the atmosphere are an integral and inevitable part of exploration, production and processing operations. In 2016, the emissions that were reported were the following: 1.8 mil tons of methane (CH_4), 822 thousand tons of non-methane volatile organic compounds (NMVOC), 363 thousand tons of Sulphur dioxide (SO_2) and 709 thousand tons of nitrogen oxides (NO_X). *Figure 3.2.1.*, not only shows that the emissions of CH_4 are the largest, but also that during the year 2016, the emissions of CH_4 were augmented significantly.

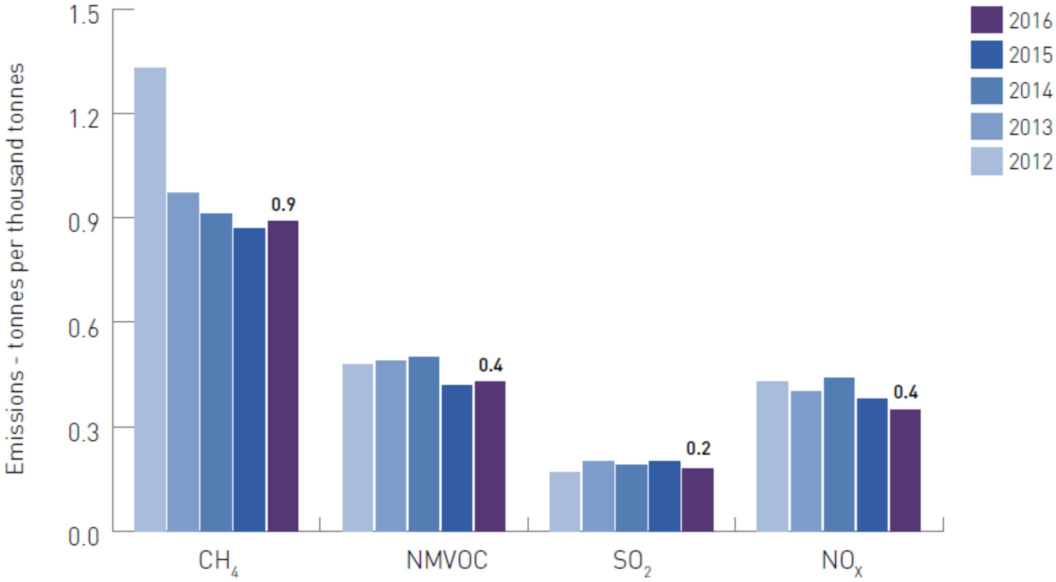


Figure 3.3.1: Atmospheric emissions per thousand tons hydrocarbon production for the time period 2012–2016 *(Source: IOGP, 2017).*

- ***Energy consumption***

Production of oil and gas requires large quantities of energy. In 2016, it was reported that the average consumption was 1.4 gigajoules of energy per ton of hydrocarbon produced. Energy consumption varies depending on the specific local circumstances and the operational conditions.

- ***Flaring***

Flaring is the controlled burning of hydrocarbons produced. It includes the controlled and safe burning of gas that is not used or exported due to safety or technical reasons or due to lack of export infrastructure. In 2016, 12.9 tons of gases were flared for every thousand tons of hydrocarbons produced. The following figure presents the tonnes of hydrocarbon flared by continent. What carries the greatest interest is the hydrocarbon flared in Africa, which is almost three times more than the overall.

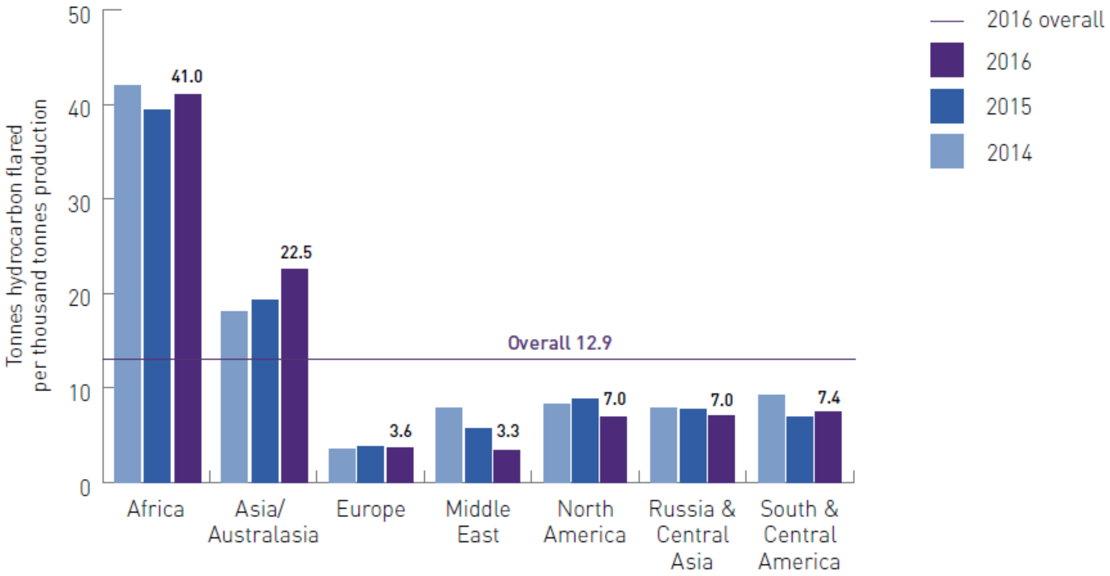


Figure 3.3.2: Hydrocarbon flared per unit of hydrocarbon production, by region *(Source: IOGP, 2017).*

➢ *__Water discharges__*

Water discharges are associated with exploration and production operations. The quality of produced water discharges is measured in terms of oil content. In 2016, the average concentration of oil in produced water was 5.8 mg/l for onshore discharges. The following figure indicates that in N. America and in Russia and C. Asia, the oil content in water discharges is extremely high compared with other regions.

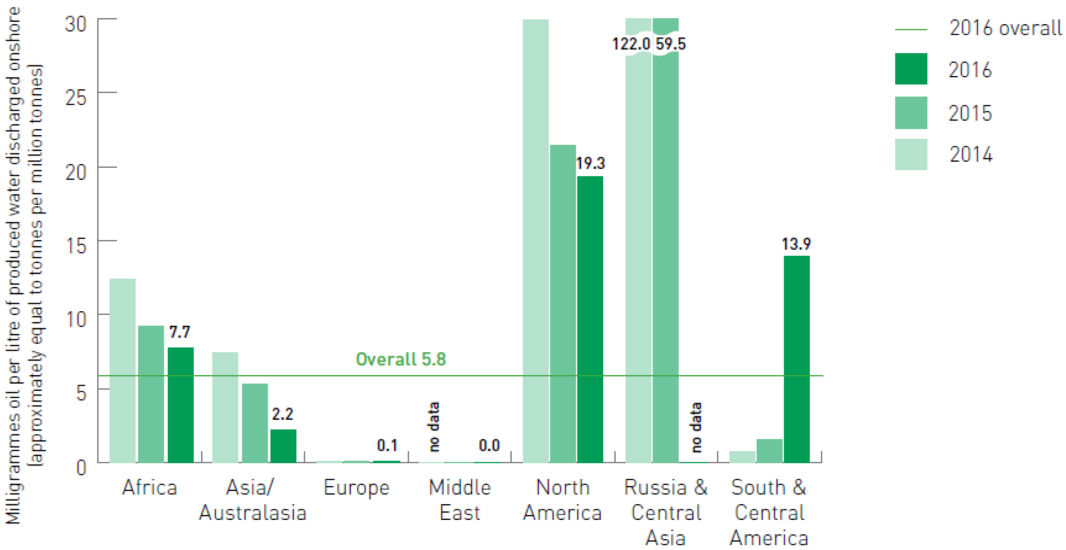


Figure 3.3.3: Oil content of produced water discharged, by region *(Source: IOGP, 2017).*

3.3.1 Oil spillages and accidents

Crude oil spills include spills of liquid petroleum produced directly from the oil and gas infrastructure, whereas refined oil spills consist of oil products (*Nuka Research, 2013).* The following figure shows the number of incidents caused per year. Regarding the carried product, the *figure 3.3.1.2* demonstrates that the majority of the incidents led to oil spillage.

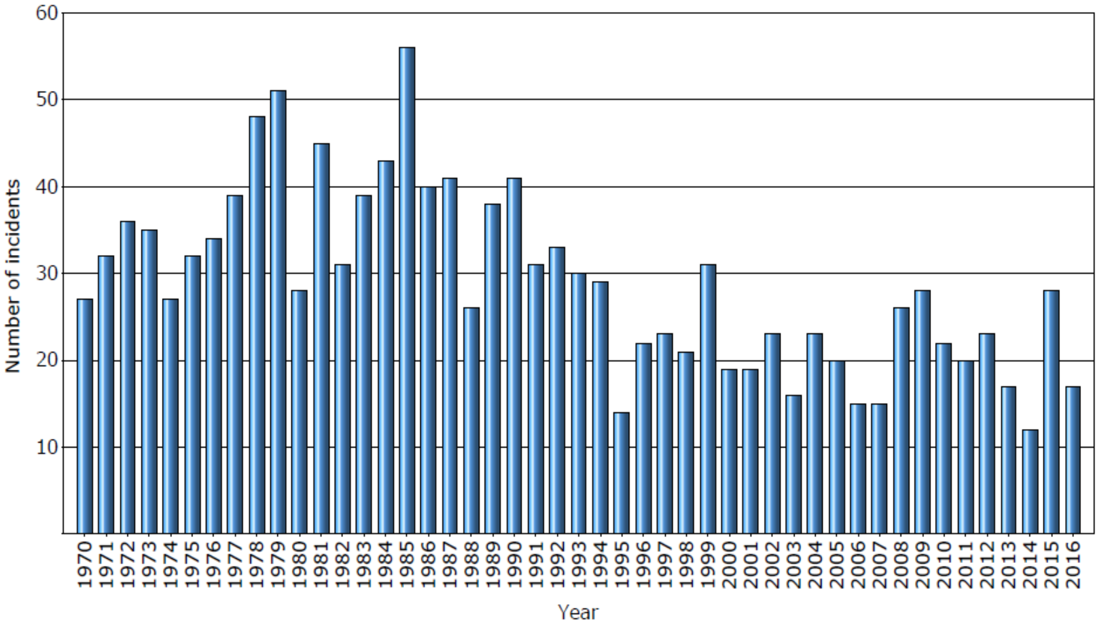


Figure 3.3.1.1: Number of incidents per year *(Source: EGIG, 2018)*

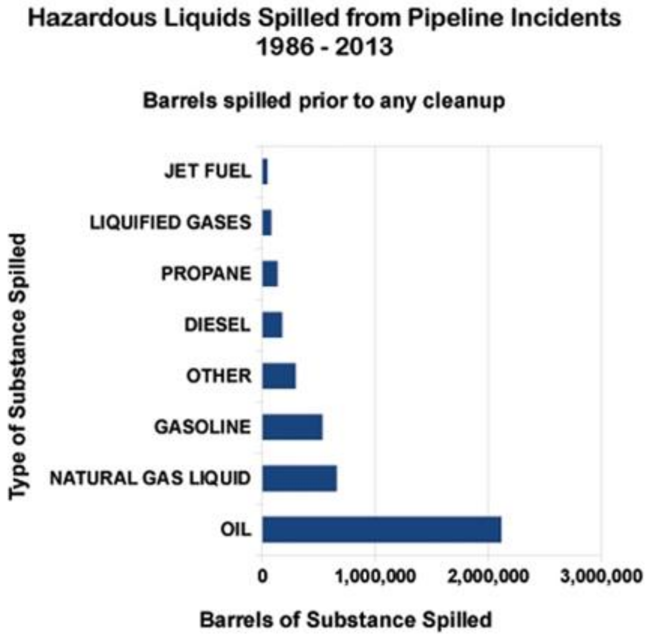


Figure 3.3.1.2: High rates in oil accidents, regarding the carried product *(Source: https://www.biologicaldiversity.org/).*

Through the years there have been registered many accidents with pipelines. *Figure 3.3.1.3* indicates the factors responsible for pipeline accidents. Pipelines are used for the transport of large quantities of oil and its products, as well as natural gas. Through this process, spills are more prone to happen, since pipelines are highly submitted to corrosion activity, not to mention that many pipelines are used long after their engineering life span (estimated to last 15 years) *(https://www.livescience.com).* Besides the characteristics of the pipeline, the oil production volume and the pipeline length, which contribute to high oil spill occurrence rates, human factor can also be the cause of an accident (*Nuka Research, 2013). Figure 3.3.1.4* presents the human errors that could lead to an accident. For example, the number of work hours by people employed in the industry could be related to spill occurrence. Apart from that, Natural hazards, such as earthquakes, floods, and landslides, can be initiating events for accidents in pipeline systems with potentially adverse consequences on the population, the environment, and the economy *(Girgin and Krausman, 2016).*

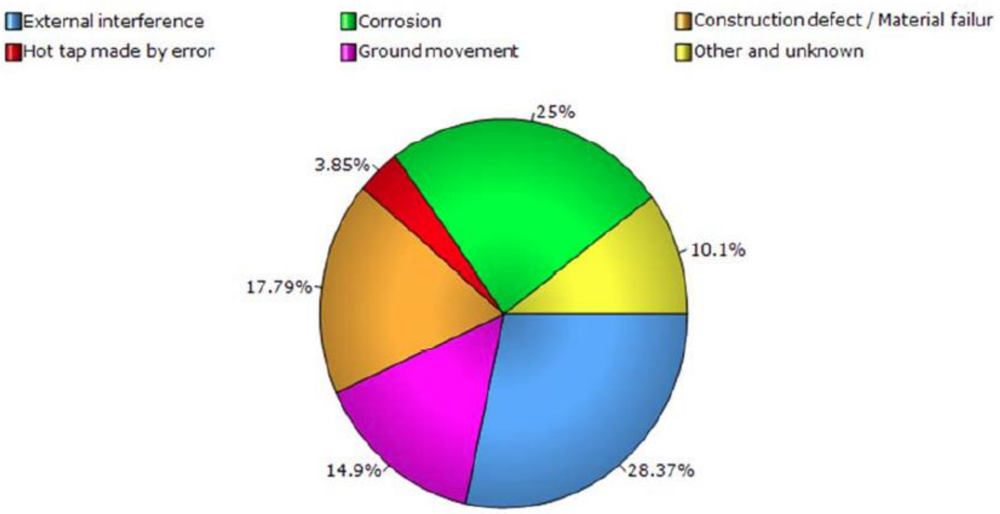


Figure 3.3.1.3: The distribution of pipeline accidents by cause, for the years 2007-2016 *(Source: EGIG, 2018).*

Classification of human error based on Kontogiannis and Embrey (1992)
• Action errors: No action was taken/ wrong action was taken. • Checking errors: Checks were omitted/ wrong checks were made. • Retrieval errors: Required information was not available/ wrong information was received. • Transmission errors: No information was sent/ wrong information was sent/ information was sent to the wrong place. • Diagnostic errors: Misinterpretation of an abnormal event. • Decision errors: Wrong decision was made.

Figure 3.3.1.4: The interrelation of a human error to the occurrence of an accident *(Source: Alkhaldi et al, 2017).*

According to *the U.S. Office of Pipeline Safety* database, it had been estimated that 67 million gallons of crude oil, gasoline, and other petroleum products leaked from U.S. pipelines in the last decade. Since United States of America is a country with large pipeline systems, this can justify the rate and the number of incidents. Sometimes accidents can be inevitable. There are over 70,000 miles of crude oil pipelines, most of them underground, carrying around one billion gallons of oil every day from production fields to refineries. Some incidents within the U.S.A borders and outside are described below.

❖ ***North & South Dakota (USA)***

Both states, but mostly North Dakota has been plagued with many pipeline spills. According to federal government data cited by the Center for Biological Diversity, oil pipeline spills in the US state of North Dakota have resulted in $40 million in property damage. Also there have been pipeline leaks of crude oil and other hazardous liquids at least 85 times since 1996, which literally means four spills a year. In July 29 of 2013 a large spill of crude oil occurred in MountRail County, under the Tesoro Pipeline. There were spilled approximately 20,600 barrels of crude oil into a North Dakota wheat field near Tioga, close to the Canadian border. It ranks among the biggest U.S. spills in recent years. Tesoro Logistics, the pipeline operator responsible for cleaning up the spill, spent $42 million and two years mopping up and processing the contaminated soil. Tesoro implemented a new technology that evaporates the oil from the soil, instead of removing contaminated earth. Till now, it's taken nearly five years of cleanup work, and there is still plenty to be done. Additional pipeline spills throughout the state, are: *(https://www.sciencealert.com)*

- The 18^{th} of May, 2016, 400 barrels of oil leak out in Bowman County. To the same event is added an additional leak of 2,500 barrels, due to a brine leak outside the facility (*https://eu.usatoday.com).*
- The 5^{th} of December 2016, Billings Country spill leaked 4,200 barrels of crude oil into Ash Coulee Creek and the surrounding countryside, due to a fault in the Belle Fourche Pipeline *(ibid).*

Additionally, in South Dakota in 2017, a crude oil spill from the Keystone Pipeline emerged that was turned out to be nearly twice as big as first reported. More than 9,524 barrels spilled onto farmland when the pipeline broke near Amherst in Marshall County. The pipeline runs through North Dakota from Canada into Oklahoma and Illinois. According to the U.S. Department of Transportation, this extravagant number made the spill the seventh-largest onshore oil spill since 2010 *(ibid).*

Photo 3.3.1.1: Contamination of a stream from a spill of the Tesoro pipeline in N. Dakota in 2013 (left), Spill of the Keystone oil pipeline leak in South Dakota in 2017 (right).

Because of the accidents that have already been happened, the people are strongly concerned about the potential impacts of new establishments in the area. They are afraid of new accidents and leaks that will result in significant impacts to water resources. One of the biggest rivers of the county, Missouri, which carries tremendous water supply, crosses the states of North Dakota and South Dakota. Native Americans that populate the area, leading a nomadic lifestyle, have opposed to the pipeline, under the assertion that the pipeline would threaten sacred burial grounds, as well as the quality of water in the area. Even a low oil spill probability threatens the Missouri River and lakes. The impacts of residual chemicals on natural resources like land, water, and wildlife linger, will need great time and effort to be eliminated. The larger the spill, the longer the effects last and the deeper the environmental harm reaches *(https://undark.org).* To soothe any opposition and objection, the University of North Dakota conducted a research, whose results are shown through the figure below. It is worth noticing that even though the production gets increased year by year, the spills stay at the same level. For this purpose, there are taken under consideration extra measures. Well pads are built using several of layers of clay and liners to protect the soil and water resources below it. Likewise, liquid petroleum and natural gas transported by pipeline include protective barriers and monitoring systems, allowing products to safely reach their destination 99.999 percent of the time (*https://energyofnorthdakota.com/).*

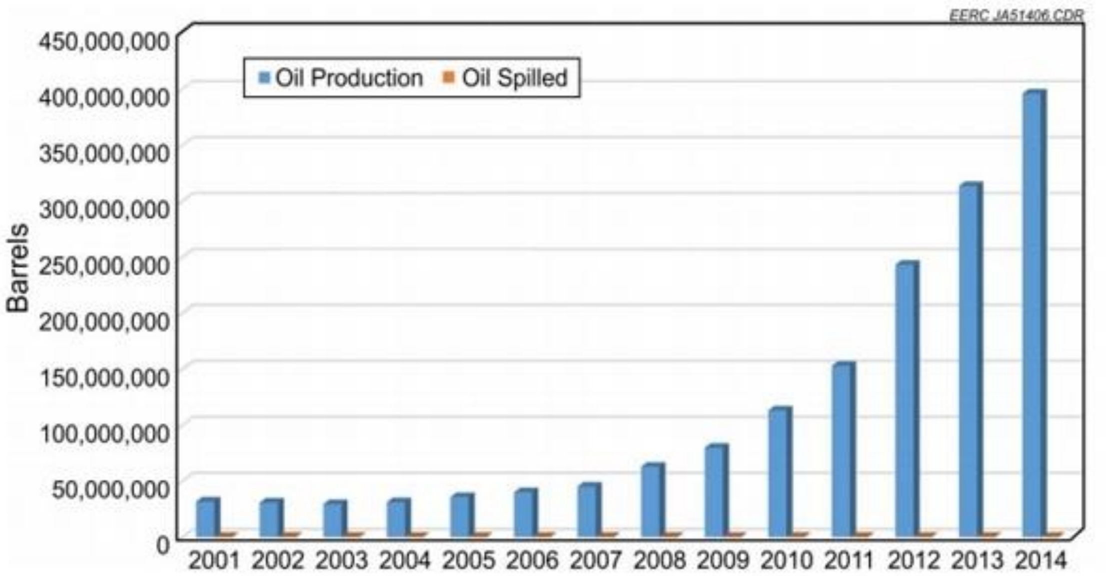


Figure 3.3.1.5: Research by the University of North Dakota Energy and Environmental Research Center in 2015 regarding the oil spill incidents by year *(Source: https://energyofnorthdakota.com/).*

❖ ***Texas (USA)***

From a survey conducted in 2016, the daily average of oil production in Texas was nearly at the highest rate since the late seventies. There were close to 179,000 wells producing a daily average of 2,663 Mbbls/day. At the same time, Texas is one more region of the U.S.A. that shares many environmental concerns. The biggest environmental problems that plague Texas are poor air and water quality, resulting from the pollution by oil refineries and oil spills. To combat the effects of water and air pollution in the state, Texas General Land Office created the Oil Spill Prevention and Response Program, an agency dedicated to stop, contain and clean up the potential oil spills *(https://eu.usatoday.com* and *https://www.epa.gov).*

Nonetheless, Texas still keeps a high record of oil spill incidents. The following oil spills are considered to be the most severe ones. On October 11th of 2010, an incident occurred with a spill of 10,200 barrels crude oil, by the Centurion Pipeline in Levelland, while on June 4th of 2011, 12,229 barrels of crude oil were spilled by the Enterprise Crude Pipeline in Chico. The cost of the damage was calculated at approximately $1,472,079. Additionally, on January 27th of 2011, 6,911 barrels of crude oil were spilled by Enterprise Crude Pipeline LLC in Iola. The cost of the damage was calculated at $4,834,962. After five years, another “large scale” oil spill occurred in Sweetwater, Texas. On August 29th of 2016, 8,600 barrels of crude oil were spilled by the Sunoco Pipeline. The estimated cost reached the number of $4,017,900 *(https://eu.usatoday.com).*

Furthermore, on January 30th of 2017, 14,285 barrels of crude oil were spilled by Enterprise Crude Pipeline, in Anna. The pipeline was ruptured when a contractor accidentally cut a high pressure oil line, leading to an inevitable spill. The cost was estimated at $2,346,925. Houston-based Enterprise Products Partners and Canada-based Enbridge are the ones responsible for the transportation of crude oil between Cushing, Oklahoma, and the Texas Gulf Coast. Enbridge, which operates less than 300 miles of hazardous liquid pipeline in Texas, has reported one oil pipeline incident over the past 10 years. It should be mentioned that the incident became worldwide when the Wall Street Journal reported that the spill bumped global oil prices up 2 percent *(http://ketr.org).*

Further on, a gasoline spill of 5,272 barrels occurred on August 31th of 2017, by the Magellan Terminals Holding LP, in Galena Park. The estimated cost reached the number of $1,292,026. Moreover, another severe incident to add on the list could be the spill of almost 119,047 barrels of gasoline from two storage tanks along the Houston Ship Channel due to the Hurricane Harvey's floodwaters *(https://eu.usatoday.com).*

❖ ***Michigan (USA)***

In the state of Michigan there was a large incident in 2010. In particular, a spill of crude oil emerged on the 26th of July, by the Enbridge Energy. The spill happened throughout the area of Marshall and Kalamazoo. The pipeline operated by Enbridge (Line 6B) burst and flowed into Talmadge Creek, a tributary of the Kalamazoo River. The pipeline was carrying heavy crude oil from Canada's Athabasca to the United States. Unfortunately, after the spill, the volatile hydrocarbon diluents evaporated, leaving the heavier bitumen to sink in the water column. 56 km of the Kalamazoo River were closed for clean-up until June 2012. The volume of the spill was estimated to be around 23,809 barrels *(https://www.epa.gov).*


Photo 3.3.1.2: Pictures taken during the clean-up of the Kalamazoo River, 2010 *(Source: http://naplesherald.com/ andhttps://www.mlive.com/).*

❖ **Illinois (USA)**

Further on, in the state of Illinois, on the 9th of September of the same year took place a second incident. This was the second Enbridge pipeline spill during that summer. The volume of this oil spill was estimated to be approximately 6,430 barrels *(https://eu.usatoday.com).*

❖ **South Carolina (USA)**

Regarding the accidents that occurred in the lower states, there were 4 crucial incidents. In the state of South Carolina, where were spilled more than 8,800 barrels of gasoline. The spill happened on the 8th of December of 2014, in Belton. The leak was discovered about a mile outside of Belton in a 26-inch diameter pipe, by the Plantation Pipe Line Company, which runs 3,100 miles from Louisiana to Washington, D.C *(https://eu.usatoday.com).*

❖ **Alabama(USA)**

In addition, in Alabama two spill incidents occurred in the interval of two months. On the 9th of September of 2016, there was a gasoline pipeline leak in the area of Helena. The 36-inch Colonial Pipeline was estimated to supply the east coast of the United States with up to 40 percent of its gasoline supply. The loss was calculated at 7,370 barrels. The major problem arose almost two months later, on October 31th, during the explosion of the pipeline. Flames were soaring over the forest about a mile west of where the pipeline burst in September. That rupture led to gasoline shortages across the South *(https://www.cbsnews.com).*

❖ **Arkansas (USA)**

In 2013, in the Magnolia Refinery in Arkansas a pipeline rupture occurred, which caused an oil spill of 15,000 barrels of crude oil, into the Little Corney Creek. The creek runs towards the town of Magnolia. The resulting oil slick was approximately 2,4 km long on the surface of the water, about 32 km north from the Louisiana state border. The United States Environmental Protection Agency (EPA) classified this pipeline rupture as a major spill. The incident occurred on the 9th of March by the Lion Oil Trading and Transportation, Inc. *(https://eu.usatoday.com).*

❖ There are also other three incidents that should be at least mentioned, regarding the volume of the spill *(https://eu.usatoday.com):*

- Oct. 13, 2014: 189,378 gallons of crude oil. By the Mid-Valley Pipeline Co., in Mooringsport, Louisiana.
- Oct. 23, 2016: 319,326 gallons of crude oil. By the Enterprise Crude Pipeline LLC, in Cushing, Oklahoma.

- Jan. 19, 2017: 420,378 gallons of crude oil. By the Tallgrass Pony Express Pipeline, in Logan County, Colorado.

❖ **Prudhoe Bay (Alaska)**

In general, at the Prudhoe Bay oil field (Trans-Alaska Pipeline) almost a spill per day is detected. Since 1996 more than 409 spills have been reported. Over 1,3 million gallons spilled between 1996 and 1999, most commonly diesel, which is toxic to plant life, and crude oil. Besides the air pollution and the aggravation of the greenhouse effect, hydrocarbons pose a high risk to the wildlife. The oil industry on Alaska's North Slope emits annually approximately 56,427 tons of oxides of nitrogen, which contribute to smog and acid rain, while the emission of 24,000-114,000 tons of methane, and contribute to the devastation of the greenhouse effect *(http://arcticcircle.uconn.edu).*

The extraction of oil in Prudhoe Bay Alaska led to the construction of a 1000 km pipeline through permafrost. Oil began reaching Valdez during the summer of 1977, and the pipeline was delivering over a million barrels a day. In 2006, 1000m^3 were spilled over 8000m^2 of permafrost making it the largest oil spill on Alaska's North Slope. Investigations showed that 10km of pipeline were badly corroded and needed to be replaced. This naturally led to shut-down. The pipeline that caused the spill was owned by the BP Exploration, Alaska (BPXA). Within the first two weeks cleanup processes were applied in order for all the liquids to be removed. There was a good and fast spill response, despite the fact that the spill was the largest oil spill on Alaska's North Slope to date. Contaminated gravel and most of the vegetative layer in the area was removed and backfill was brought in from the tundra.

Photo 3.3.1.3: Workers clean up the oil spill at BP's Prudhoe Bay oil fields in Alaska, 2006 *(Source: BLOOMBERG).*

❖ ***Niger delta (Nigeria)***

The Niger Delta covers an area of 20,000 square kilometers and it is considered to be one of the most biodiverse places on the planet, comprising four ecological zones: coastal barrier islands, mangrove swamps, freshwater swamps and lowland rainforests. Since oil extraction started in the 1950's, many oil spills have occurred throughout the entire Niger Delta region in Nigeria. The oil spills were caused from facilities and pipelines, abandoned infrastructure, transport and artisanal refining *(Palsson, 2014).* Some spills are caused by sabotage and thieves, while the majority of the incidents happened because of the poor maintenance by oil companies. According to the Annual Statistical Bulletin, for the year 2014, the 65.13% of oil spilled was due to sabotage; 17.38% was by yet to be determined causes; 14.35% was a result of natural accidents, corrosion, equipment failure and human error; while 3% was due to undefined circumstances *(Ikenna et al., 2016).*

Photo 3.3.1.4: Pollution of the Niger Delta *(Source: https://www.dw.com/).*

The Nigerian government estimated a 2 million barrels spill of oil into the Niger Delta through the years 1976 to 1996. However, the World Bank states that the true quantity of petroleum spilled into the environment could be as much as ten times the officially claimed amount. 70% of these spills occurred off-shore and 6% spilled on land. In particular, in July 1979 the Forcados tank 6 Terminal in Delta state incidence spilled 570,000 barrels of oil into the Forcados estuary polluting the aquatic environment and the surrounding swamp forest. In August 1983 Oshika village in River state witnessed a spill of 5,000 barrels of oil from Ebocha Brass (Ogada-Brass 24) pipeline which flooded the lake and swamp forest. The area had previously experienced an oil spill of smaller quantity; 500 barrels in September 1979 with mortality in crabs, fish and shrimp. The Ogada-Brass pipeline oil spillage near Etiama Nembe in February 1995 spilled approximately 24,000 barrels of oil which spread over freshwater swamp forest and into the brackish water mangrove swamp. More recently, in 2008 and 2009, when a 55-year-old pipeline owned by Shell ruptured twice, 600,000 barrels of crude oil were spilled into the surrounding creeks of the Niger Delta. Projects are being held for the clean-up, but the recovery of contaminated areas is prevented due to the chronic character of the contamination *(Kadafa 2012 and Nwagbo 2017).* One representative example is the oil spill in Ogoniland. By accordance with *Shell Nigeria*, in 2017, 92 sites were remediated and certified (out of 251 identified for this work), 32 of which in Ogoniland. During 2017, 84 new sites requiring remediation were identified, of which eight are in Ogoniland. In total, there are 243 oil spill sites that require remediation (*https://www.shell.com.ng).*

Photo 3.3.1.5: Oil Spill in Ogoniland Region *(Source: https://www.business-humanrights.org/).*

According to *Shell Nigeria*, oil spills due to crude oil theft and sabotage of facilities, as well as illegal refining, cause the most environmental damage from oil and gas operations in the Niger Delta. Crude oil theft on the pipeline network resulted in a loss of about 9,000 barrels/day in 2017. The number of sabotage-related spills in 2017 increased. To prevent crude oil theft, the government has provided air and ground surveillance, and since 2012, the Shell Petroleum Development Company (SPDC), has managed to control more than 950 theft points *(https://www.shell.com.ng).*

Photo 3.3.1.6: Vandalized pipe *(Source: https://guardian.ng/).*

It is also crucial to analyze the severity of oil spills on culture, local economy and on the life within communities. Oil spillages in the unique Niger Delta states have caused extensive social underdevelopment which ultimately strikes the Nigerian national economy. This indicates that instead of an increase in social and economic conditions, there is as loss of sources of livelihood. The most severe social impacts in those areas are the violence and upheaval, as well as the reduction in tourism and hospitality industries *(Oshienemen et al, 2017).*

The levels of contamination are high enough to cause severe problems to the ecosystem and human health. The spills have contaminated the Niger Delta regions water, air, and plants with trace metals that have accumulated in crops and harmful, potentially carcinogenic hydrocarbons such as polycyclic aromatic hydrocarbon and naturally occurring radioactive materials. Along with the various effects oil pollution has had on the Niger Deltas vegetation and agricultural land, oil pollution has also impacted the health of the local residents. The ingestion, contact, and inhalation of constituents of spilled crude oil may have acute and long-term health implications (*Nwagbo, 2017).* A new study, the first to link environmental pollution with newborn and child mortality rates in the Niger Delta, shows that oil spills occurring within 10km of a mother's place of residence doubled neonatal mortality rates and impaired the health of her surviving children *(Bruederle and Hodler, 2017).*

❖ ***Kuwait (Iraq)***

Communities, ethnic groups or even entire countries, want to obtain control over the lands where oil is produced or has potentials of discovery. An extreme example, but yet very representative since it is one of the largest oil spills, is the Gulf War oil spill in 1991. The war was the cause for the tremendous oil spill that influenced land and sea. The impacts of this unfortunate incident were immeasurable.

Photo 3.3.1.7: The Gulf War Oil Spill in Kuwait *(Source: http://www.greenpeace.org/).*

❖ ***Fergana Valley (Uzbekistan)***

An older incident but yet with the same significance, is the blow out of the well 5 in the Mingbulak oil field of the Fergana valley, Uzbekistan, on March 2nd, 1992. A massive terrestrial oil spill started on that day to become the worst in the history of Asia. The oil coming out of the well caught fire and was burning for two months. The blowout resulted in the release of 35,000 barrels to 150,000 barrels per day. With more than 2,000,000 barrels, the Fergana Valley disaster is part of the world's ten largest oil spills (*http://www.energyglobalnews.com).*

❖ ***Former Soviet Union***

There have been also many crude oil spills from pipelines in the former Soviet Union (FSU). In particular, there were identified 113 crude oil spill accidents, whose cause of spill and exact location are presented in the following table.

Table 3.3.1.1: Number of oil spill accidents by location and cause of Spill, FSU 1986–96 *(Source: https://esmap.org).*

	Cause of spill*						
Location	Mecha-nical failure	Corrosion	Operatio-nal error	third-party activity	Natural hazard	Unknown	Total by location
Azerbaijan	1	—	—	1	—	1	3
Belarus	—	—	—	—	—	1	1
Kazakhstan	—	—	—	—	—	1	1
Latvia	1	—	—	1	—	—	2
Russia, East	8	7	2	9	—	18	44
Russia, Far East	1	—	—	—	1	—	2
Russia, North	5	2	—	1	—	3	11
Russia, South	4	2	2	3	1	3	15
Russia, West	1	—	—	—	1	3	5
Russia, Central	7	2	3	2	—	10	24
Ukraine	3	—	—	—	1	1	5
Total by cause	31	13	7	17	4	41	113

To conclude, impacts can be aggravated by natural phenomena, or caused by them. According to *Girgin and Krausman (2016)*, the main natural hazard categories are the following:

- Meteorological hazard, such as tornado, heavy rain, storm, tropical cyclone, high wind and lightning.
- Geological hazard, such as earthquake, landslide, subsidence, frost heave, etc.
- Climatic hazard, such as hot or cold weather, freeze and drought.
- Hydrological hazard, such as flood and stream erosion.

The main natural hazard category is the meteorological with 36% contribution. Geological hazards are the second most important category with 26%, followed by climatic and hydrological hazards with 24% and 14%, respectively *(ibid)*. A representative example of the main category is the impacts caused by the tropical cyclone in Louisiana. Hurricane Katrina in August 2005, was responsible for the failure of a storage tank at the Murphy Oil USA refinery and the creation of the Murphy oil spill. More than 1 million gallons of mixed crude oil were released from the Murphy refinery tank. The flooding enabled the spreading of spilled oil over larger areas, affecting about 1,700 homes in several residential neighborhoods *(https://www.environmentalpollutioncenters.org)*. This example highlights that even if all standards are taken into account, some outcomes could never be estimated.

Photo 3.3.1.8: The tremendous destruction in Louisiana, with the distribution of the Hurricane Katrina in August 2005 *(Source: UCSUSA)*.

Similar outcomes were originated from the Hurricane Harvey, another tropical cyclone. In general, due to the hurricane, the wastewater storage tanks were damaged causing the mixing of wastewater with floodwater. The spill was about 10,988 barrels. Part of the spill flowed into a nearby waterway where dozens of petrochemical facilities are located. However, the possible long term health effects and environmental contamination are yet not clear *(https://environmenttexas.org)*.

Photo 3.3.1.9: Clear signs of oil contamination after the hurricane Harvey's floodwaters *(Source: https://www.businessinsider.com)*.

4. Environmental management of onshore oil activities

4.1 Impacts and their consequence

For each of the stages, for onshore activities, a range of environmental aspects is examined, as described in previous session. The following analysis is based on *Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016*, and it's a systematic approach for the characterization of the risk based on the likelihood that an incident will occur and the potential consequence of that incident. The scores of risk are the product of likelihood multiplied by consequence. The highest scores are awarded to combinations of high likelihood and catastrophic consequence (and vice versa). The risk score permits risks and impacts to be compared.

			Consequence of Incident					
			1	2	3	4	5	
			Slight	Minor	Moderate	Major	Catastrophic	No data
Likelihood of Incident	1	Extremely Rare	1	2	3	4	5	Not classifiable
	2	Rare	2	4	6	8	10	
	3	Occasional	3	6	9	12	15	
	4	Likely	4	8	12	16	20	
	5	Highly Likely	5	10	15	20	25	
		No data	Not classifiable					

Colour	Level of Risk	Score
	Low	1 – 4
	Moderate	5 – 8
	High	9 – 12
	Very High	15 – 25

Figure 4.1.1: Classification of risk level *(Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

More specifically, <u>likelihood</u> is assigned as:

o *Extremely rare*

No known events of the risk under review have taken place within the industry within Europe or elsewhere.

o *Rare*

Incidents may have occurred within the industry (Europe or elsewhere) previously but at a very low frequency.

o *Occasional*

These are incidents that should not occur under standard practices. These incidents will however be more common place, for example those that are known to have happened historically at several companies during operations in Europe or elsewhere.

o *Likely*

These are incidents which are likely to occur. The frequency of events is more difficult to predict, but should be assumed to have happened several times per year at different operating companies.

o *Highly likely*

These are incidents which are highly likely to occur. The frequency of events is more difficult to predict, but should be assumed to occur several times per year (or all the time) in each well location. Incidence of the issue is well documented within the industry with good practice guidelines warning of its potential.

Consequence is assigned as:

o *Slight*

These are incidents which have immediate but short term impact on the environment which naturally remediate after a few days/weeks. Where the severity is 'low', it would have direct impact on environment with noticeable effects, but these would be limited.

o *Minor*

These are incidents which will have both an immediate and longer term effect (weeks or months) and take a number of months for the environment to naturally remediate, or require physical intervention to remediate the effects. The level of severity is again 'low', i.e. they will have a noticeable effect on environment without causing widespread death of flora and fauna.

o *Moderate*

These are incidents which will have an immediate and long term (years) effect on the environment. Severity will be 'low', including chronic but not fatal effects on the environment. Effects will be likely to last for several years without direct intervention but dilution rates will limit the effects of the raised levels.

o *Major*

These are incidents which will have an immediate effect both on a short term basis (hours/days) and also longer term (weeks/months/years). However these events can be remediated with direct intervention within a number of weeks of the incident. The level of severity in these incidents will be high causing widespread death to flora and fauna with significant impact on ecosystems and local populations, but with managed response the effects should be short term.

o *Catastrophic*

These are incidents which will have an immediate and prolonged effect on the environment lasting several years. The effects of the incident will be severe and widespread causing death to flora and/or fauna or irreversible damage to the environment for several years. The incident is also potentially likely to damage natural resources in a near-irreversible fashion, requiring several years for the environment to return to pre-incident conditions.

The summary of risk characteristics for every stage can be found in appendix A. A meta-analysis of risk characteristics has been conducted in terms of the likelihood and the consequence of environmental aspects, without expected mitigation measures, in each stage. The results are presented below.

In general, the first six figures have been created regarding the maximum and the average value in terms of likelihood, consequence and risk. The following figures have been made in order to distinguish which processes can draw the values to their highest level, at each and every stage of the petroleum activity.

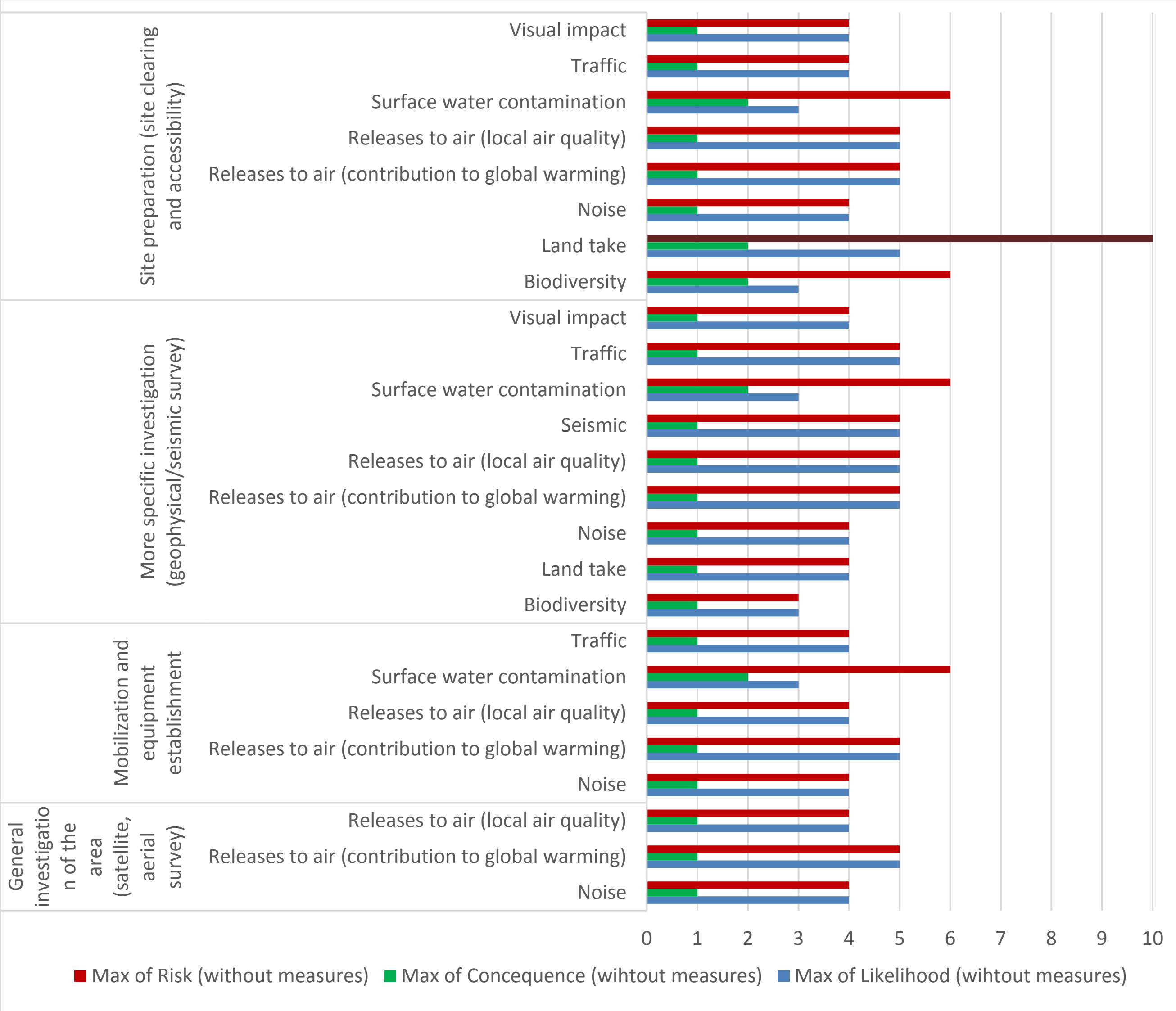


Figure 4.1.2: A meta-analysis for stage 1, without the expected mitigation measures. Connection between risk, consequence and likelihood for every impact (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

According to *Figure 4.1.2*, the level of risk gets extremely high at stage 1 only during *Site Preparation*. Specifically, without applying the measures, the impact with the greatest risk of happening is the impact of land take. In every other case the risk is high, because every activity in petroleum industry carries a risk of failing and provoking impacts. Further down it follows a thorough description.

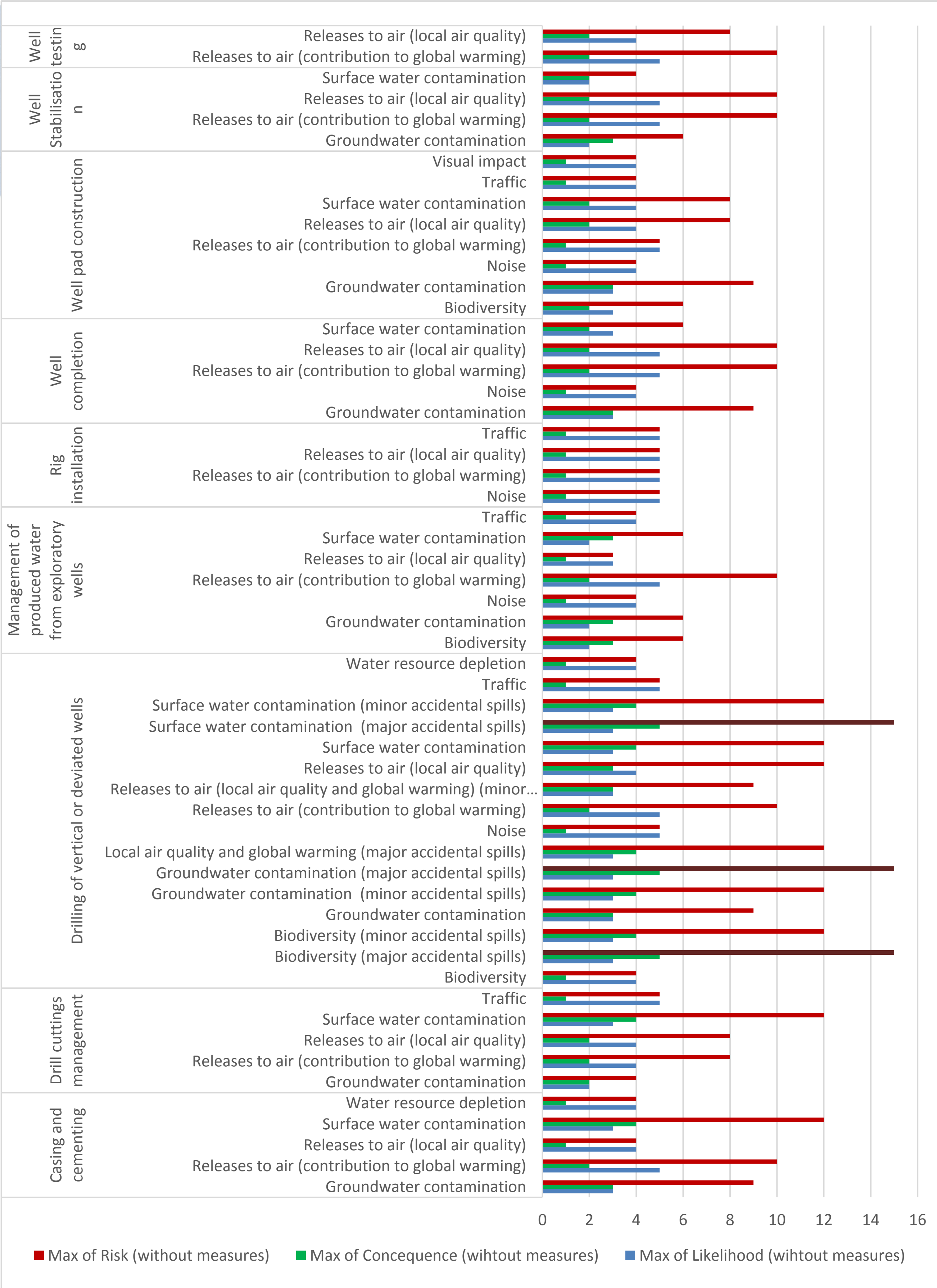


Figure 4.1.3: A meta-analysis for stage 2, without the expected mitigation measures. Connection between risk, consequence and likelihood for every impact (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing*).

Following, according to *Figure 4.1.3*, in stage 2, the consequence and therefore the risk appear to be higher than the previous stage. This could be justified by the fact that during stage 2 the petroleum activities are more difficult and complex to be completed than those of stage 1. It must be highlighted that in case of an incident (minor, but mostly major), all the values appear to be escalated. Since stage 3 includes activities with great intervention and risk, as in stage 2, the values of *Figure 4.1.4* present the same fluctuation. Further down it follows a thorough description.

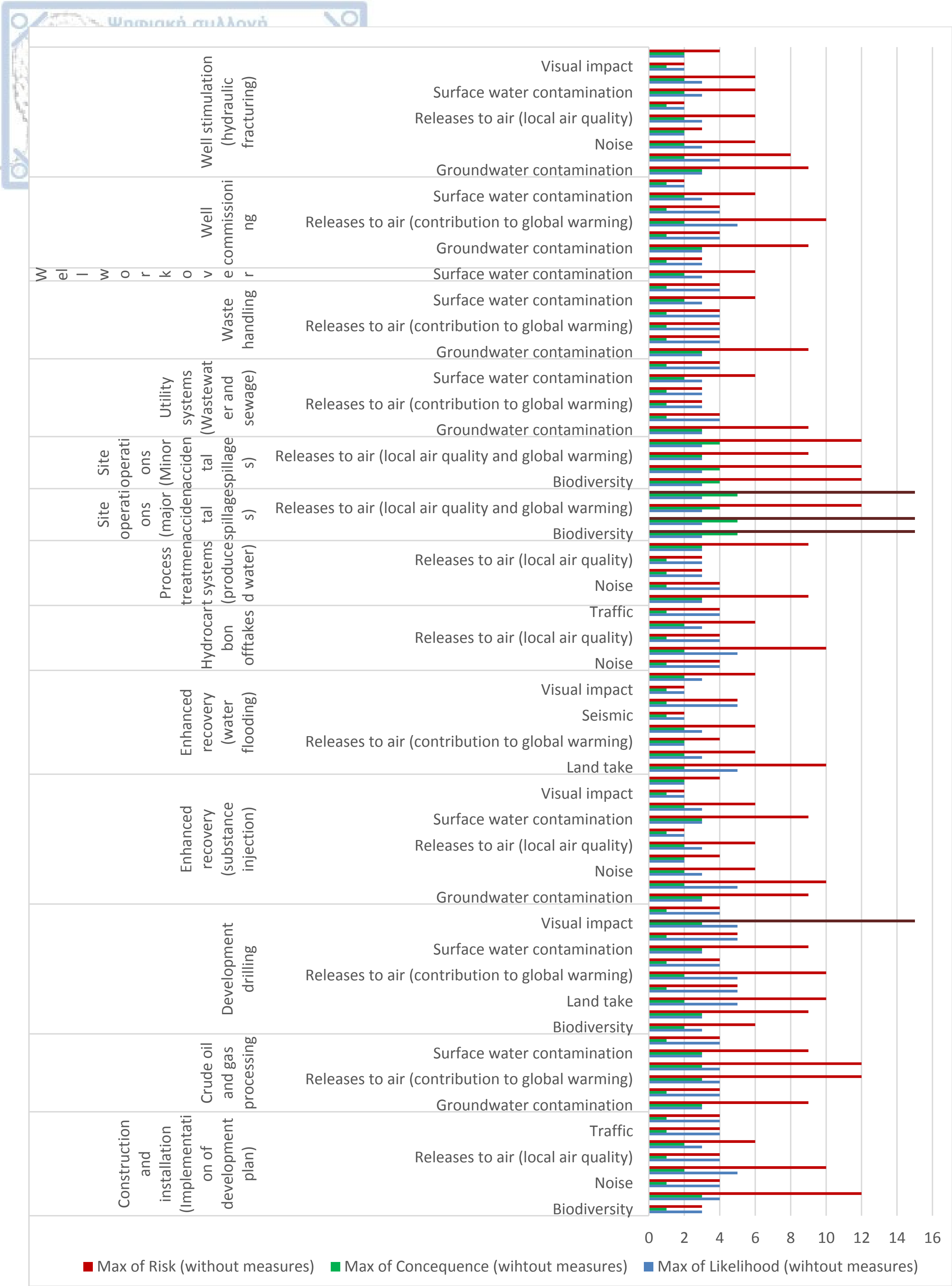


Figure 4.1.4: A meta-analysis for stage 3, without the expected mitigation measures. Connection between risk, consequence and likelihood for every impact. (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

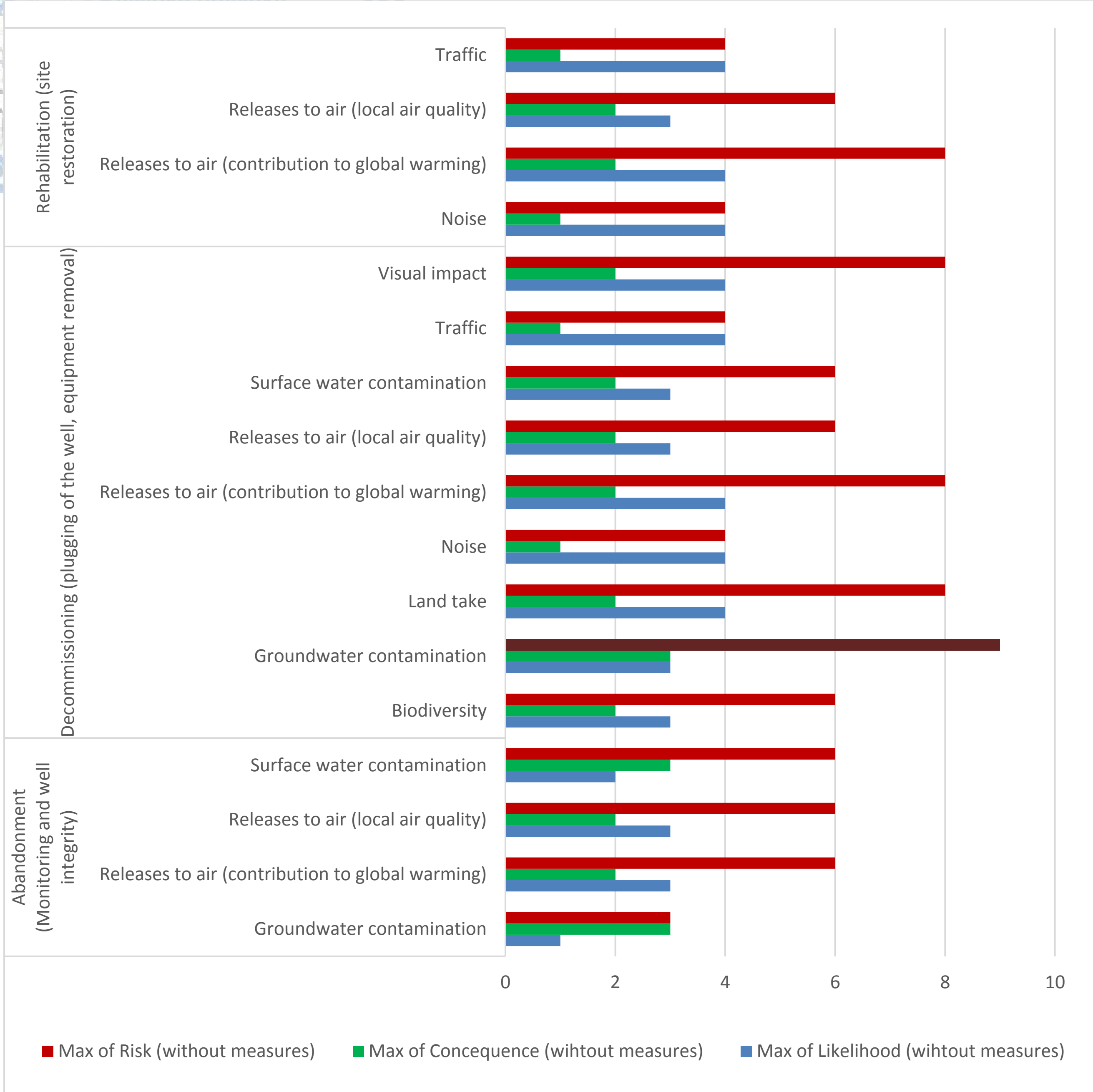


Figure 4.1.5: A meta-analysis for stage 4, without the expected mitigation measures. Connection between risk, consequence and likelihood for every impact.(*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

On the contrary, the petroleum activities of stage 4 carry less difficulties and impacts than the aforementioned. In accordance with *Figure 4.1.5*, risk exceeds the average value, with regard to the groundwater contamination.

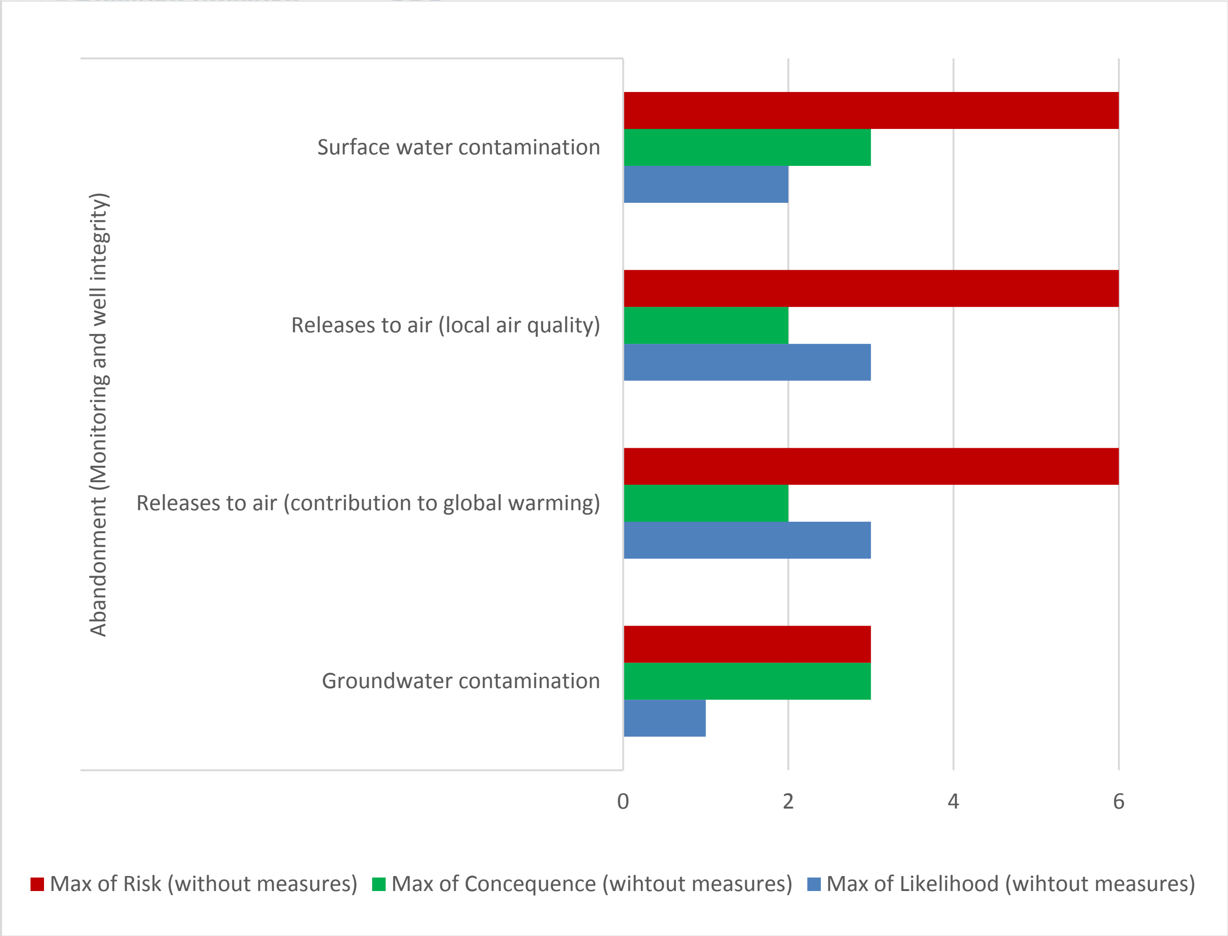


Figure 4.1.6: A meta-analysis for stage 5, without the expected mitigation measures. Connection between risk, consequence and likelihood for every impact (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

According to *Figure 4.1.6*, the results can verify the conclusions of the previous stages. Since stage 5 is the stage of monitoring and maintenance, low risk values were anticipated.

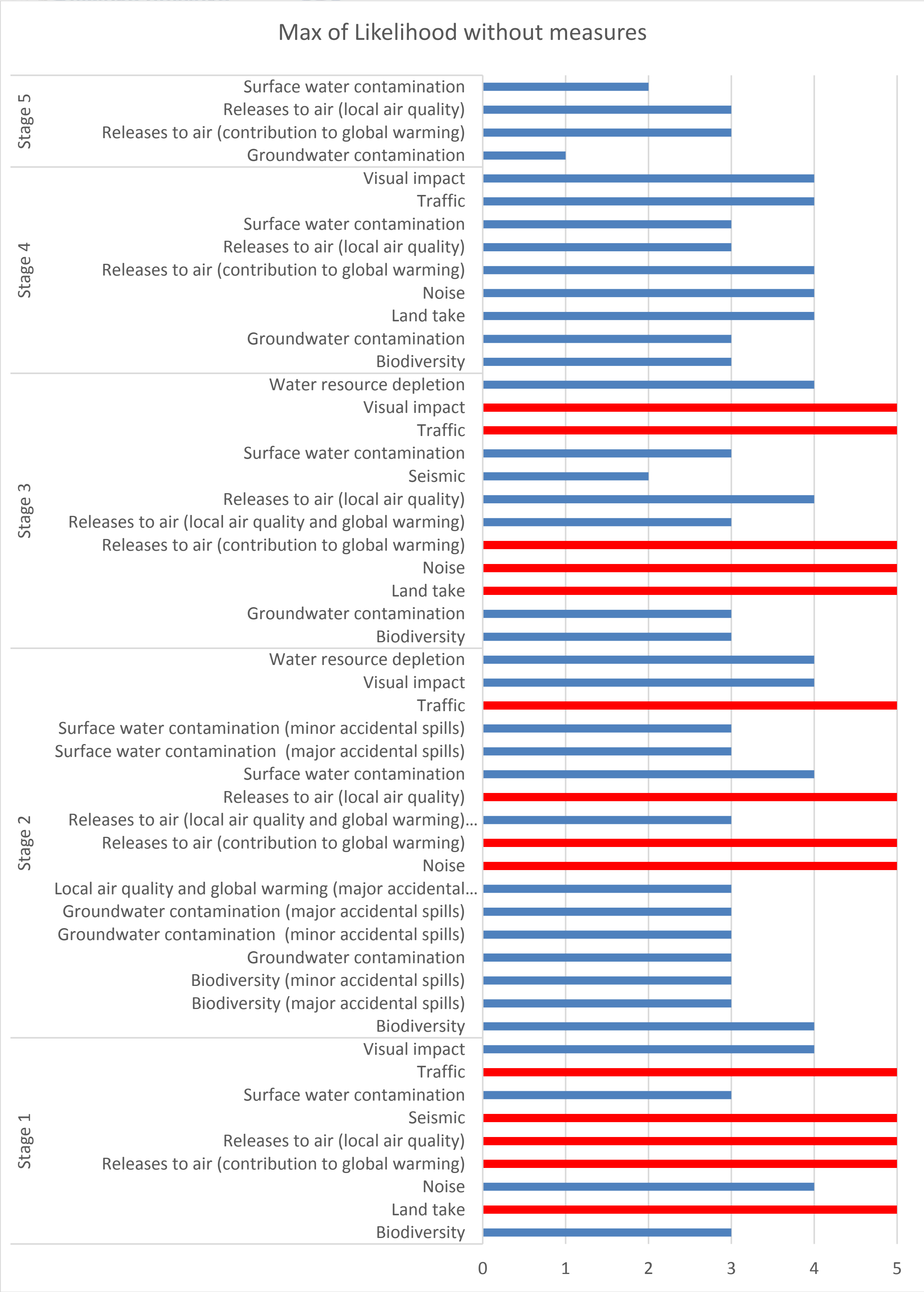


Figure 4.1.7: A meta-analysis of every impact in terms of likelihood (max of likelihood) for each stage, without the expected mitigation measures (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

To begin with, by taking under consideration the *Figure 4.1.7*, the three first stages of petroleum activity carry the greatest possibility (above #4) of provoking a significant impact. The results seem extremely high because the figure is based only on the maximum value of likelihood occurred in at least one process of each stage. Therefore, during the first 3 stages, the impacts with the greatest likelihood of happening are: traffic, visual impact, noise, land take and releases to air (air quality and contribution to global warming). This happens because some processes tend to draw the likelihood of provoking an impact to its maximum level. In any case, the likelihood of provoking an impact depends on what activities are mostly done in every stage. For example, during stage 1, the likelihood of provoking a seismic impact gets higher due to the execution of seismic surveys. More data are presented below.

In correspondence with what was analyzed above, *Figure 4.1.8* demonstrates likelihood rates for every impact, but this time the rates are based on the mean values of likelihood of all processes in each stage. For this reason, the results seem to be decreased, reaching only at average values of likelihood. Undoubtedly, the impacts with the greatest likelihood are again: traffic, visual impact, noise, land take and releases to air (air quality and contribution to global warming).

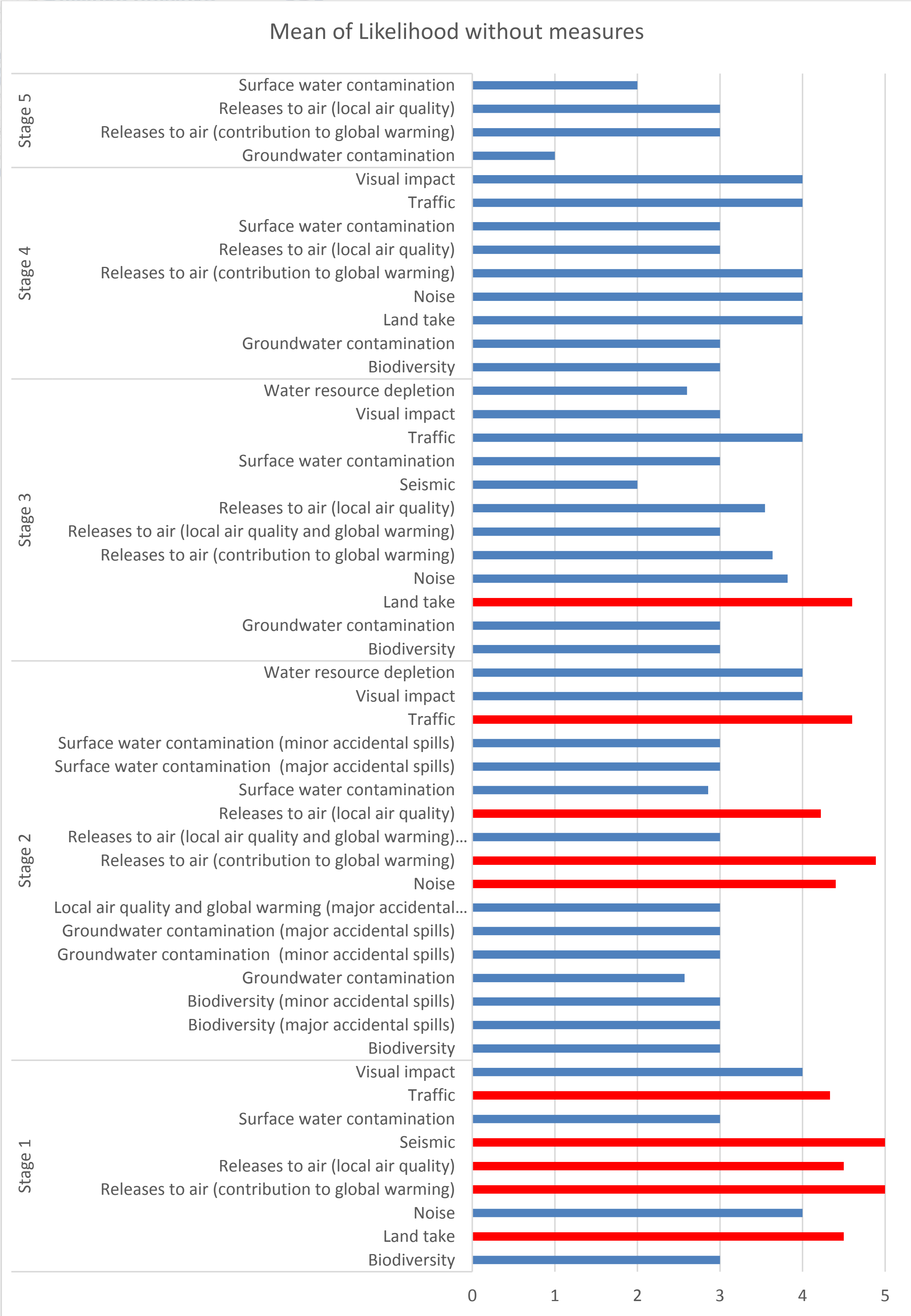


Figure 4.1.8: A meta-analysis of every impact in terms of likelihood (mean of likelihood) for each stage, without the expected mitigation measures (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

Regarding the difference between the values of the maximum and average likelihood, there are some processes in the petroleum activity, which are linked with the highest (maximum) possibility of provoking a significant impact.

In other words, in stage 1, the processes that influence and draw the likelihood of provoking a significant impact to its highest values (#5) are:

- The "**Site preparation**", which increases the value of releases to air (local air quality and contribution to global warming).
- The "**More specific investigation**", which increases the value of releases to air (local air quality and contribution to global warming), traffic and seismic.
- The "**Mobilization and equipment establishment**" and the "**General investigation**", which increases the value of releases to air (contribution to global warming).

Moreover, in stage 2, the processes that influence and draw the likelihood of provoking a significant impact to its highest values (#5) are:

- The "**Well testing**", the "**Well pad construction**", the "**Management of produced water**" and the "**Casing and cementing**", which increases the value of releases to air (contribution to global warming).
- The **Well stabilization**", the "**Well completion**" which increases the value of releases to air (local air quality and contribution to global warming).
- The "**Rig installation**", which increases the value of releases to air (local air quality and contribution to global warming), traffic and noise.
- The "**Drilling of vertical or deviated wells**" which increases the value of traffic, noise and releases to air (contribution to global warming).
- The "**Drill cuttings management**", which increases the value of traffic.

Lastly, in stage 3, the processes that influence and draw the likelihood of provoking a significant impact to its highest values (#5) are:

- The "**Development drilling**", which influences the noise, the land take, the traffic, the releases to air (contribution to global warming), and the visual impact.
- The "**Enhanced recovery-Water flooding**", which increases the value of traffic and land take.
- The "**Enhanced recovery-Substance injection**", which influences the landtake.
- The "**Well commissioning**", the "**Hydrocarbon offtakes**" and the "**Construction and installation**", which increase the value of the contribution to global warming.

To conclude, when the value it's in maximum pick in more than one process, then the average value of likelihood of provoking a significant impact will maintain high values.

The consequences of the potential impacts are analyzed below.

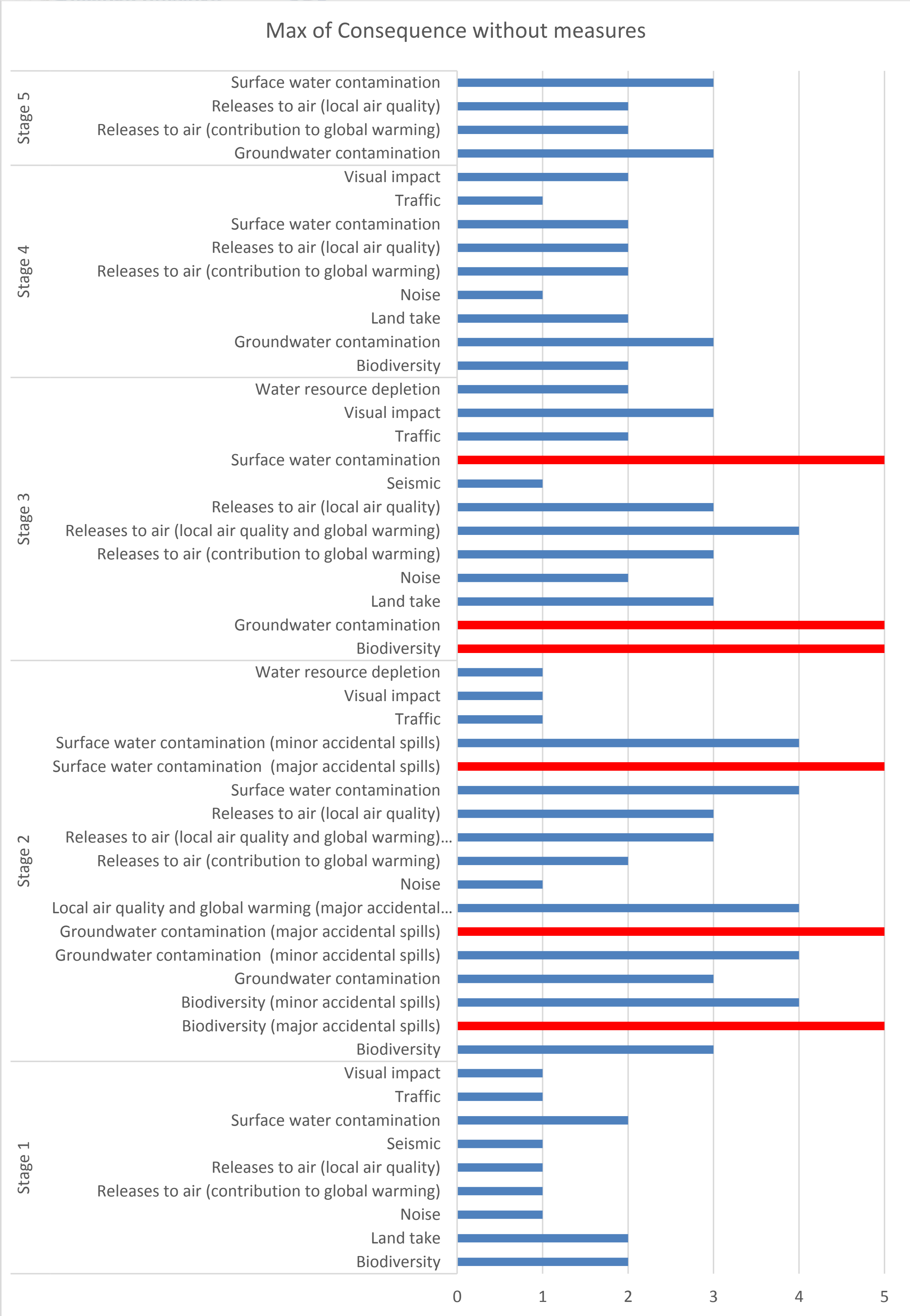


Figure 4.1.9: A meta-analysis of every impact in terms of consequence (max of consequence) for each stage, without the expected mitigation measures (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

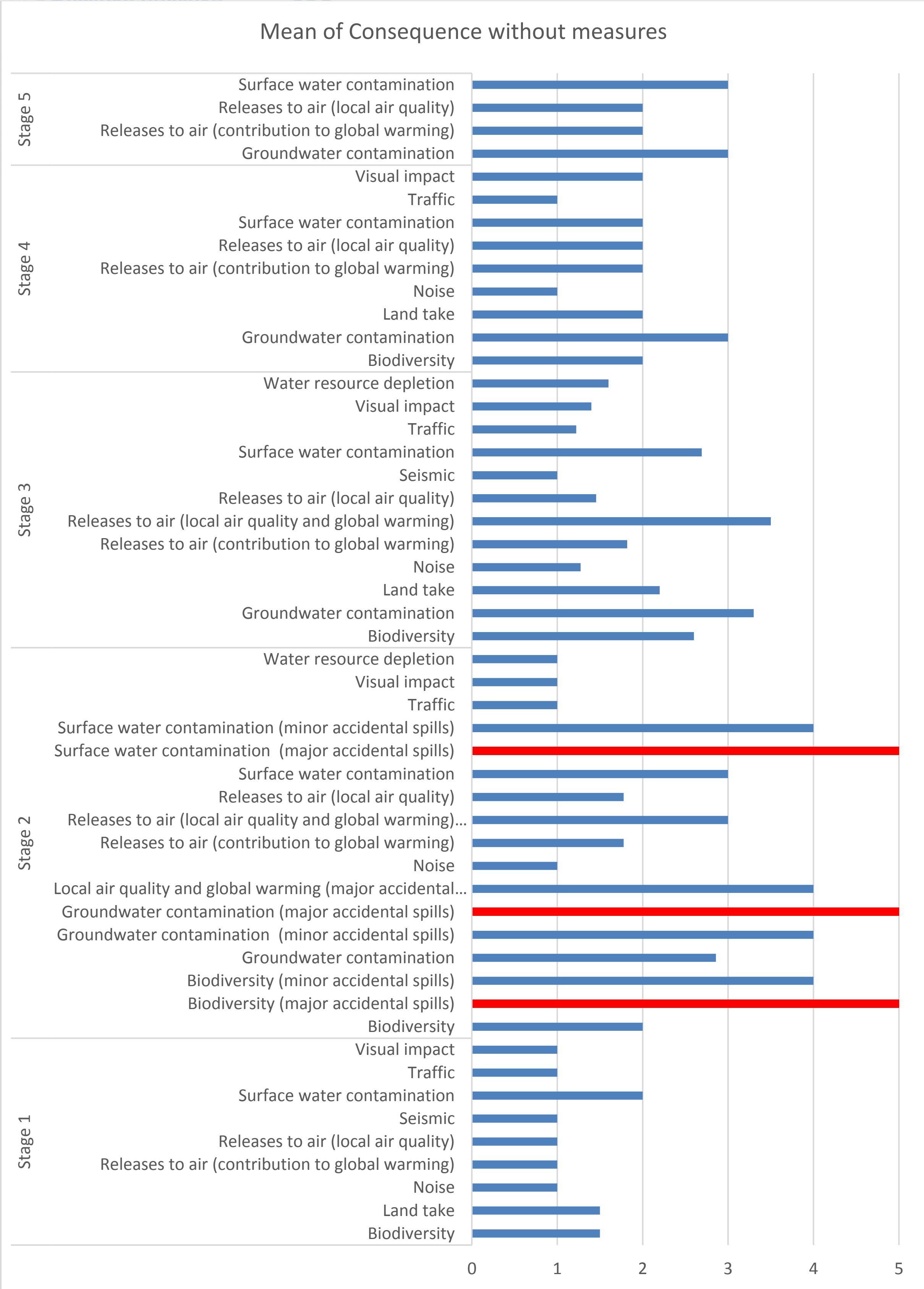


Figure 4.1.10: A meta-analysis of every impact in terms of consequence (mean of consequence) for each stage, without the expected mitigation measures (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

According to *Figure 4.1.9*, which is based on the maximum values of consequence, only stage 2 and 3 of the petroleum activity bring the greatest consequences (above #4). The results seem extremely high because the figure is based only on the maximum value of consequence occurred in at least one process of each stage. Therefore, during stage 2 and stage 3, the impacts with the greatest consequence are: contamination (surface water and groundwater) and biodiversity. In any case, the consequence depends on the activities that are executed and under which scale. A large scale intervention to the environment will provoke greater consequences. For example, in case of an accident, such as a major accidental spill, the results escalate and finally deteriorate the incident.

On the other hand, *Figure 4.1.10*, which demonstrates the mean values of consequence of all processes in each stage, the results seem to be decreased, reaching only at average. However, in case of a major spill, the consequences would maintain the maximum values, without falling, even if the calculations are made regarding average values.

More specific, regarding the difference between the values of the maximum and the average consequence, there are some processes in the petroleum activity, which are linked with the highest (maximum) impact consequence. In other words, in stage 2, the process that influences and draws the consequence to its highest value (#5) is the "**Drilling of vertical or deviated wells**", which in case of a major spill increases the surface water contamination, the groundwater contamination and the biodiversity. Likewise, during stage 3, the process that affects the most the value of consequence is the "**Site operations**", which in case of a major spill increases to its peak the surface water contamination, the groundwater contamination and the biodiversity.

To conclude, in case of a major incident during the process of drilling at stage 2, the average consequence maintains its maximum value, without dropping, while at stage 3, the average consequence seem to be off the red area, which means that the values managed to drop.

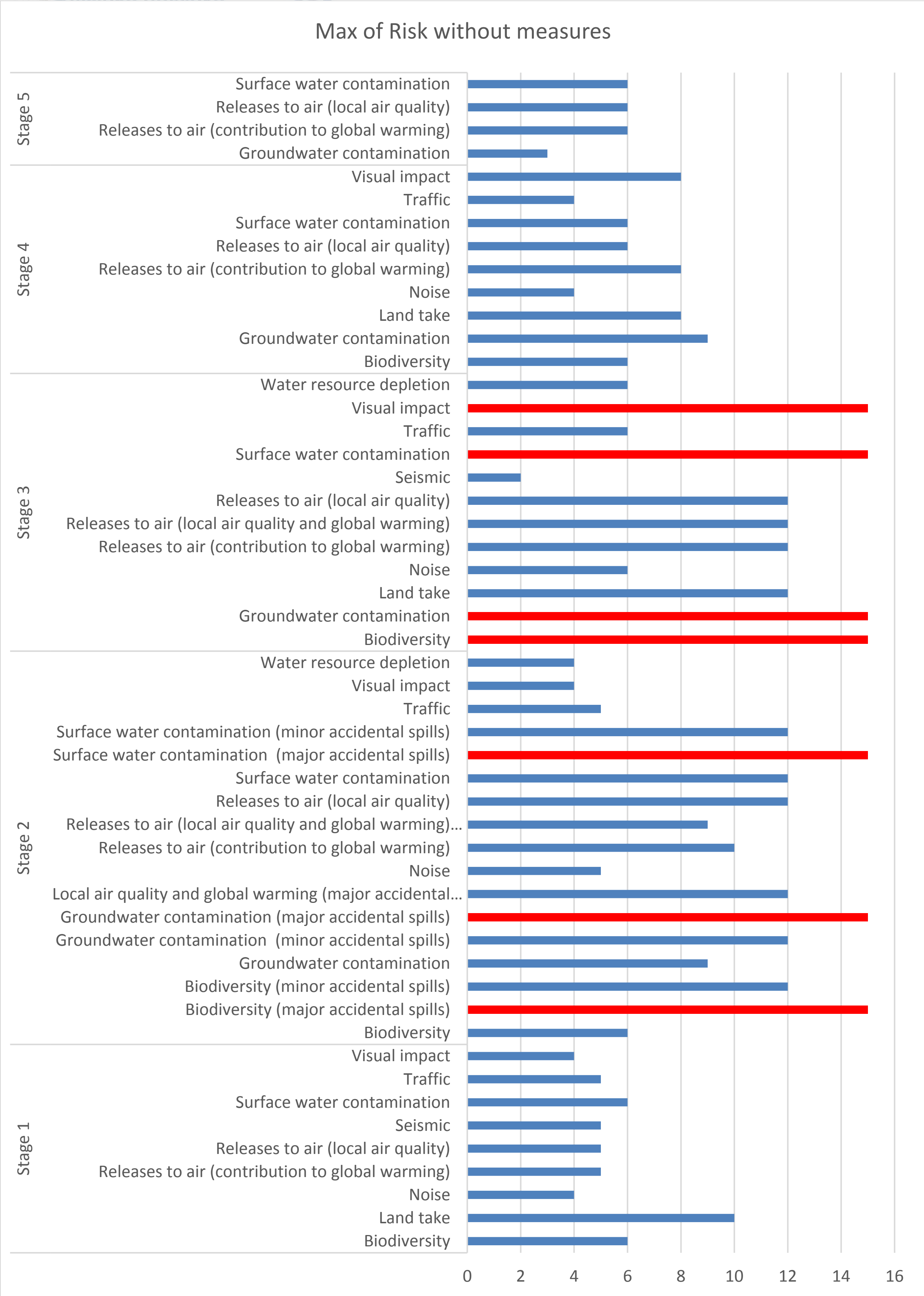


Figure 4.1.11: A meta-analysis of every impact in terms of risk (max of risk) for each stage, without the expected mitigation measures (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

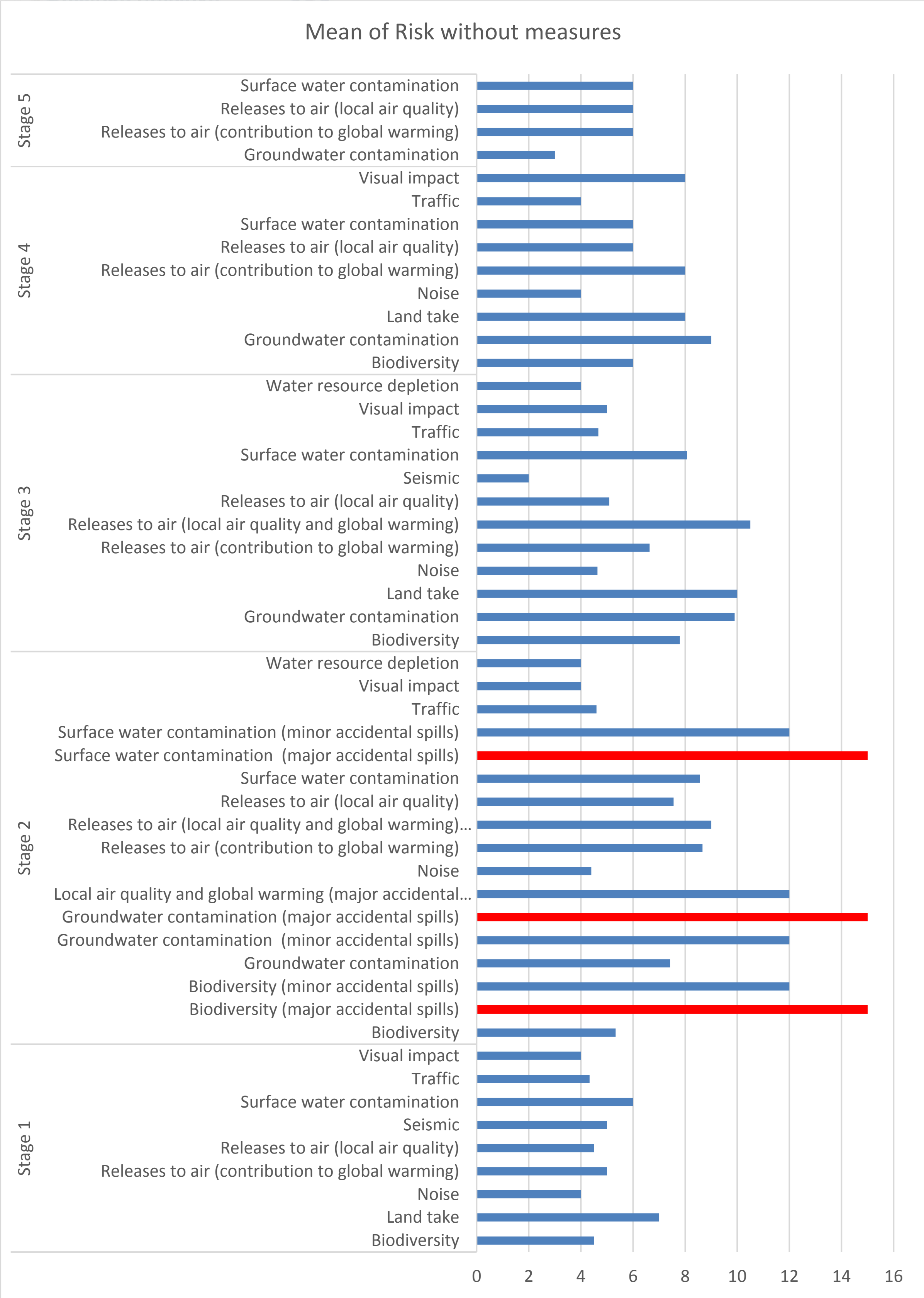


Figure 4.1.12: A meta-analysis of every impact in terms of risk (mean of risk) for each stage, without the expected mitigation measures (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

According to *Figure 4.1.11*, which is based on the maximum values of risk, only stage 2 and stage 3 carry the greatest risk (higher than 14). Therefore, during these stages, the impacts with the greatest risk of happening are: contamination (surface water and groundwater), visual impact and biodiversity. The results seem extremely high because the figure is based only on the maximum value of risk occurred in at least one process of each stage. In any case, the risk depends on what activities are executed and under which scale. For example, a large scale intervention to the environment carries a greatest risk.

On the other hand, in *Figure 4.1.12*, which demonstrates the average values of risk of all processes in each stage, the risk in stage 3, not only decreased, but also got off the red zone (maximum level). The only values that remained high refer to impacts that are caused only in case of a major spill.

Regarding the difference between the values of maximum and average risk, there are some processes in the petroleum industry, which affect to the full the values of risk to increase. In particular, in stage 2, in case of a major spill, the process of "**Drilling of vertical deviated wells**", increases the values of surface water contamination, groundwater contamination and biodiversity to maximum. Additionally, in stage 3 the process that affects the most the value of risk is the "**Site operations**", which in case of a major spill increases to its peak the surface water contamination, the groundwater contamination and the biodiversity. Moreover, during the process of the "**Development drilling**", the visual impact seems to enter the red zone.

Finally, the process that affects the most the risk value is the "**Drilling of vertical deviated wells**" process, due to the fact that even considering the average values, the risk of provoking surface water contamination, groundwater contamination and biodiversity remains to its maximum value.

4.2 Protection measures

4.2.1 General data

Over the past three decades the growth of environmental awareness and interest has grown immensely. In order to avoid a failure and decrease the adverse environmental impacts, a correct plan is considered crucial. The first step in developing a suitable technology management plan is to understand the source and the possible effects. *(Figure 4.2.1.1)*

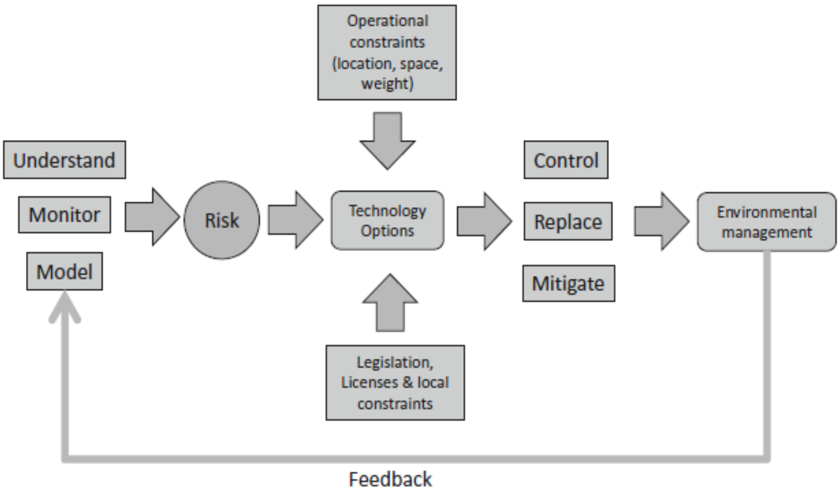


Figure 4.2.1.1: The process of setting-up a possible technology management plan *(Source: Orszulik, 2016).*

After the set-up of a plan, a monitoring is required. Major environmental issues related to oil and gas development have been addressed through countless global and regional treaties, national laws and a number of administrative regulations and management frameworks, promulgated by individual countries and multinational organizations such as UN agencies, the World Bank, and International Finance Corporation (IFC), to promote natural resource conservation and pollution control. Associated with this growth of interest, legislations were formed, such as ***The Environmental impact assessment (EIA)***. The following figure demonstrates its process step by step *(UNEP, 1997 and Winther, 2013).*

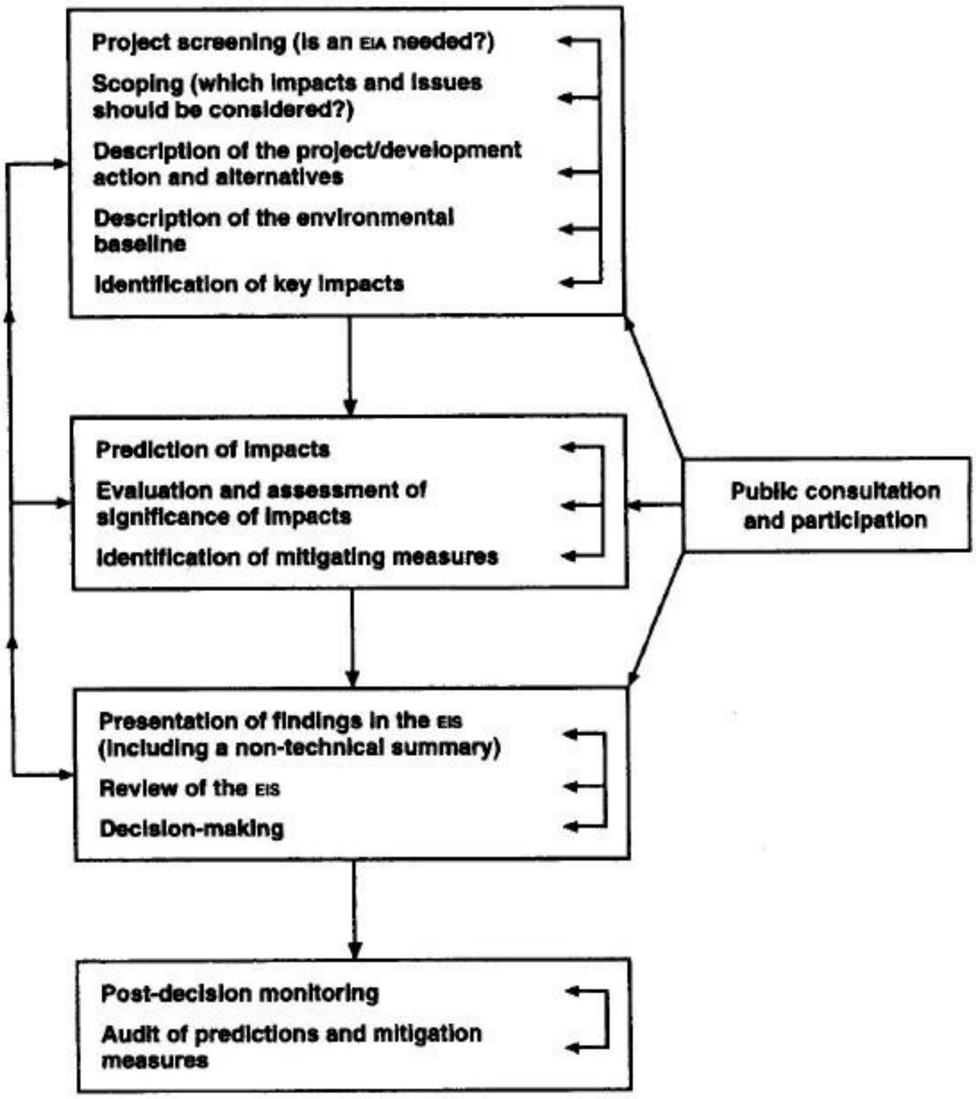


Figure 4.2.1.2: Steps in the EIA process *(Source: Winther, 2013).*

The Environmental impact assessment (EIA), according to Glasson et al., (2005), is a "systematic process that examines the environmental consequence of development actions, in advance, a cyclical activity, with feedback loops and interaction between the various steps". Projects are developed at an early stage in order all the alternatives to be considered. The consideration of alternatives ensures that the proponent has considered other feasible approaches to the project. Further, an environmental baseline is included to determine the current state of the environment prior to any development project. Then, an identification of possible main impacts is included in order to identify all significant impacts (both positive and negative). Finally, a prediction of impacts aims to identify the severity of the changes in the environment. After impacts are identified mitigating measure are introduced in order to help avoid, reduce, remedy and compensate for any adverse impact.

Additionally, the ***environmental impact statement (EIS)*** documents the information and estimates the impacts derived from various steps in the process. Prevention is said to be better than cure and an EIS, revealing many significant and unavoidable impacts, would provide with enough information that could contribute to the abandonment or the modification of a proposed development action. The EIA and EIS practices vary from country to country, study to study. One more crucial process is the ***Social impact assessment (SIA)***, which is defined by Vanclay (2002), as: "the process of analyzing (predicting, evaluating and reflecting) and managing the intended and unintended consequences on the human environment of planned interventions (policies, programs, plans, and projects) and any social change processes invoked by those interventions so as to bring about a more sustainable and equitable biophysical and human environment" *(Winther, 2013).*

4.2.2 Measures

All mentioned above aim to the eradication of impacts in the petroleum industry, as much as possible. In particular there are specific actions taken under consideration for the minimization of impacts.

To begin with, during *designing phase*, the equipment should be sized and designed to provide appropriate safety and utility, by giving consideration to adverse natural conditions and industry standards. Also, it should be designed with appropriate spill control devices, such as high/low level indicators or high/low pressure indicators, to improve safety and protection of the environment. Additionally, the anticipated time the equipment is expected to remain active should be considered. Air pollution control facilities should be installed whenever practical, economical, and technically feasible; while any variance from the manufacturer's recommended rates or pressures should be evaluated. Recyclable products should be used, as well as appropriate methods of collecting and recycling or disposing of waste generated during construction, operation, and maintenance of the facility. Operators should develop waste management plans *(Matanovic, 2014).*

A proper ***Waste Management Plan*** always is considered crucial. Waste management plans identify exactly how each waste stream should be managed. One of the first steps in developing a waste management plan is to identify the region and scope to be covered. All materials generated within the region must be identified, quantified, and characterized. The potential for a material to migrate from a site must also be considered when determining the best way to manage it. Factors like topography, hydrology, geology, soil conditions, and the presence of sources of usable water must be evaluated. Other factors that must be considered are the special needs of environmentally sensitive areas such as wetlands, rain forests, arctic tundra, arctic icepack, areas where subsidence during production may occur, urban areas, historical sites, archaeological sites, protected habitats, and sites providing habitats for endangered species. A critical step in developing waste management plans is to identify a specific action plan for handling each and every material at all sites covered by the waste management plan. The first and most important action in the waste management hierarchy is to reduce the volume of wastes generated. The next action is to reuse the wastes or materials in the wastes. Only after those actions have been completed should the remaining wastes be treated and disposed *(Reis J.C., 1996).*

During *the phase of construction and installation*, further measures should be considered. In those measures is also included the appropriate inspection by qualified personnel to ensure the avoidance of a leakage. Additionally, after the installation of a new line, all line routes should be cleaned up and restored to conditions compatible with existing land use, while the disposal of all waste should be in accordance with the regulations. All equipment should be installed according to the original design and plan. Any variations from the original specifications should be evaluated thoroughly to ensure safety of the operations. Upon completion of facilities, the original drawings or schematics should be updated, as required. Changes or modifications from the original design or drawings should be noted for future reference. Unused and excess construction materials should be properly stored or removed from the site upon completion. During construction, the site should be kept as clean and free of debris as possible. Interim reclamation consists of minimizing the footprint of disturbance by reclaiming to the extent possible all portions of the site not required for production operations *(Matanovic, 2014).*

After design, construction and installation phase starts *the operational phase*. The development of a standard operating procedure manual applicable to each major facility is considered crucial. The manual should contain information as to the equipment located at the facility, safe-operating practices for the equipment, start-up and shutdown procedures, and emergency procedures. Also, consideration should be given to the analysis of failures or malfunctions so that corrective action can be taken to minimize future environmental incidents. Pressure tests, profile surveys, and other means should be considered to meet operating safety requirements. Frequency of failure analysis should be also considered to aid in scheduling line replacements. Emergency phone numbers should be posted at the entrance to the facility, if located near a populated area *(Matanovic, 2014).*

For the minimization of atmospheric emissions, improved process control procedures, design and maintenance systems have been developed. Continuous venting of associated gas is not considered current good practice and should be avoided. The associated gas stream should be routed to an efficient flare system, although continuous flaring of gas should be avoided if alternatives are available. The principal aim is to handle flaring and venting which provide the largest amount of emissions to the atmosphere. Alternative options may include gas utilization for on-site energy needs, gas injection for reservoir pressure maintenance, enhanced recovery using gas lift, gas for instrumentation, or export of the gas to a neighboring facility or to market. For this purpose many technological advances have been developed over the years. Moreover, to minimize the emissions of Sulphur dioxide, it is suggested the use of fuel with lower Sulphur content, the up-gradation of SRU unit and the tail gas treatment, as well as the use of Leak Detection & Repair (LDAR) and a vapor recovery system *(Winther, 2013 and Matanovic, 2014).*

Appropriate steps should be taken to prevent surface and environmental damage from the use of hot oil, chemicals, and other treatments that are used to maintain lease gathering and system lines. Proper maintenance practices should be applied. Waste materials should be recycled, reclaimed, or disposed. For minimization of wastewater, the reuse and recycle of treated effluent is suggested. Significant amounts of water return to the reservoir or other deep rock formations with adequate porosity and far away from the aquifers *(Winther, 2013).* Regarding the solid waste management, there are proposed new technologies for improving recovery of oil from oily waste and also for preventing oil spillage at crude loading/unloading facilities. A sound waste management plan is important to protect human health and the environment and minimize long-term liabilities. The final option for management of wastes, after source reduction, recycling, and treatment options have been considered and incorporated, is disposal. The operator should take into consideration the long-term fate of the waste and its constituents before disposal *(Matanovic, 2014).*

Accidental spills (including oil and saltwater) can, besides potentially damaging the environment, create difficult operational, legal, and public relations problems. It is very important to conduct operations in a manner that minimizes the potential for unauthorized spills. Spill prevention, response, and cleanup procedures should be defined before storing any oil or chemicals on site or conducting activities that have a potential for a spill. The best way to avoid adverse effects of spills is to prevent their occurrence. The key factors in spill incident prevention are adequately trained supervisors and field operating personnel *(Matanovic, 2014).* In case of an oil spill, which poses one of the greater threats, an effective risk management plan (Oil Spill Contingency Plan, or OSCP), can lead to the minimization of its effects. Technology for the management of oil spills falls into two distinct categories, the recovery techniques and the oil treatment in situ. In onshore activities, the contaminated with oil soil is frequently dug up. During the in situ treatment, chemical dispersants are used that transform oil into smaller droplets where the natural action of waves and microbes break down the oil. This biodegradation technique is widely used onshore *(UNEP, 1997 and Government of Western Australia, 2016).*

In the event a spill occurs, the source of the spill should be stopped, or reduced as much as possible, in a safe manner. *Figure 4.2.2.1* covers all the possible ways to prevent a leakage with regard to the Pipeline System. The spread of the spilled substance should be controlled or restricted in the smallest possible area to minimize the adverse effects *(Matanovic, 2014).*

1.0	**Ensuring general integrity and construction quality of pipeline**
1.1	Full (100%) quality control of welding joints and assemblies during construction
1.2	Coating pipeline with three layers of a polymer to prevent formation and development of
1.3	Installation of valve systems and pig launch/trap stations
1.4	Hydrotesting of the whole pipeline system before commissioning
1.5	Use of electrochemical protection facilities
2.0	**Protection against mud flows and landslides**
2.1	Burying of pipelines to a depth of 0.5 m below the maximum scouring line, with a 5% cumulative probability of mud flow
2.2	Leveling and stabilizing of slopes, construction of water retaining structures and bearing walls
2.3	Reinstatement of natural relief to ensure stability of ground on slopes
2.4	Additional burying of pipelines by 2 meters at mud flow hazard areas coinciding in size and location with landslide areas
2.5	Construction of bearing walls at mud flow/landslide hazardous sections
2.6	Stabilizing landslides at the highest risk areas.
2.7	Control and adjustment of surface drainage to prevent or significantly reduce damping of soil with rain/thaw water.
2.8	At the landslide area additional drainage channels are made, which help to discharge water from slopes
2.9	Installation of bearing walls and leveling of slopes to decrease the landslide probability
3.0	**Avalanche protection**
3.1	Construction of avalanche breakers, curtain earth banks and snow discharge pits
3.2	Terracing of slopes with a height exceeding 10 m within the pipeline route area
3.3	Strengthening (reinforcement) of steep slopes
4.0	**Erosion control**
4.1	At the most hazardous bank erosion areas line facilities are protected from such processes by existing transport infrastructure facilities, such as motor road/railroad sections
5.0	**Earthquake protection**
5.1	Trenches of a special geometry are designed were constructed, special materials are selected for filling, as well as special seismic fault crossing angles
5.2	Seismic sensors are installed at some river crossings to monitor vibration of soil and pipelines
6.0	**Operation of the transport pipeline system**
6.1	Use of automatic ATMOS system to control and detect leakage after reaching the design condition of the pipeline system
6.2	The pipeline system is equipped with pig launch/trap stations for a periodic cleaning of the internal cavity and carrying out in-line inspection to make sure that pipeline is intact
6.3	Use of a multilevel system of safe discharge and emergency shut-down

Figure 4.2.2.1: Procedures for preventing leakage at line/site production facilities of the Transport Pipeline System *(Source: http://www.sakhalinenergy.ru/).*

In every case a number of ***Contingency Plans*** are needed to prepare a facility to minimize the impact of any foreseeable emergency. These plans describe ways to eliminate the source of the release, to assess the character, amount, and extent of the release, to identify ways of confining the release so any impacts are minimized, to recover all lost or contaminated materials, and to notify relevant regulatory authorities *(Reis J.C., 1996).* According to *Government of Western Australia, 2016,* a contingency plan may be developed through the next steps:

- *Identification of spill sources*

  In order to prevent a spill from occurring, it is important that the operator identifies and understands all potential sources of spills.

- *Preparedness*

  It is important to understand the environment and its sensitivities in order to manage a spill in the most effective way, and be prepared for an incident.

- *Response levels*

  For a quick response, need to define the incident, the trigger of the spill, and the appropriate mechanisms to terminate it.

- *Protection*

  All sensitivities that may potentially be affected by the worst case spill scenario must be identified and listed in order to understand and support the plan's priorities and strategies. Also, a map should be provided to present all the information needed.

- *Structure, roles and responsibilities*

  The plan must identify the operator's emergency response structure across all levels of incidents and provide information on the roles and responsibilities of all personnel who will play a role in the incident response. The structure, roles and responsibilities will range from in-field personnel as the initial responders, to those roles and teams in other locations which may be contacted in the event of larger scale incidents. The operator is required to provide information on how all roles interact, including details on the internal notification structure and process, to demonstrate that appropriate lines of communication are in place.

- *Trajectory modeling*

  A "current oil spill trajectory modeling" needs to be stated. It is important to understand how a spill may impact the environment. This is critical to ensure adequate response techniques are planned and implemented at the time of an incident. The plan must include information that best represents the zone of potential impact and subsequent fate of a spill for all credible scenarios (including worst case).

- *Response equipment*

  A list of equipment available on site should exist, in order for the response to be faster in the event of an incident.

- *Response personnel*

  Identification of positions and training of the personnel available to respond to an incident.

- *Contact directory*

  Operators are required to maintain a contact directory, with all the appropriate contact details.

- *Testing the OSCP*

  The Regulations require the operator to conduct and describe tests of the emergency response arrangements set out in the plan at specified intervals. The specified intervals are determined by the operator.

- *Response and Recovery*

  The response and recovery arrangements may be influenced by: the location, the type and amount of the material that was spilled, the environmental sensitivities, the equipment and capability of a response, and weather conditions.

- *Occupational health and safety*

  The plan must identify the operator's Occupational Health and Safety policy and/or procedure that will be adhered to by all personnel when responding to an incident. For this purpose general information on personal protective equipment (PPE) requirements would also be included in the plan.

Moreover, during *the phase of abandonment*, there are also measures taken under consideration in order to minimize the potential impacts to the environment. Firstly, the well should be purged and flushed, as appropriate, and then the materials that were recovered should be recycled and reclaimed if possible. Where appropriate, each outlet should be permanently sealed and all pits and surface impoundments should be properly closed. The closure must also be in accordance with any local and/or state regulations. Upon completion of abandonment activities, all disturbed surface areas should be cleaned up and restored to conditions similar to the adjacent land or to landowner requirements. Restoration of the original landform is a key element in ensuring that the effects of oil and gas development are not permanent.

With regard to all that was mentioned in this chapter it was created the following figure, which elaborates the measures that are applied during every petroleum activity, and theirs benefits.

Table 4.2.2.1: In place measures for onshore activity *(Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

Title of measure	**Description of measures**	**Benefit**
BAT technologies for low sulphur fuels in marine shipping, aircraft	Marine shipping is involved in multiple life-cycle stages of the offshore hydrocarbon exploration and production process, including surveying, transporting of the drill rig, drilling and supplying of the platform. Additionally, aircraft are used in the surveying stage of both offshore and onshore activities. BAT (Best Available Technique) technologies and low sulphur fuels may be used in the engines of relevant vessels and aircraft to increase efficiency and reduce emissions of key pollutants such as NOx, SOx and Particulate Matter (PM) in their exhaust stream.	The quantity of pollutants emitted to the atmosphere from shipping and aviation related to offshore and onshore activities are reduced. This in turn reduces contributions to ocean acidification, global warming and eutrophication. It should be noted that some abatement technologies which reduced air pollutants also reduce the efficiency of the engine, thus increasing carbon intensity.
Exclusion zones around drilling rig	Where hydrocarbon drilling rigs are in busy construction or shipping areas, exclusion zones may be established surrounding the equipment. Vehicles or vessels and personnel are not permitted to enter these zones unless they are engaging directly with the rig, thus reducing the likelihood of injury or disturbance of the drilling process.	Exclusion zones reduce the risk of collisions between vessels or vehicles and the drilling rig, which could result in a hydrocarbon spillage and associated damage to surrounding ecosystems. They also reduce the risk of personnel being injured by drilling equipment.
Bunding, protected skids, totes	Offshore and onshore sites store large quantities of diesel to generate power. A variety of chemicals and wastes are also stored as part of the hydrocarbon production process. These substances can be held in designated and protected storage areas. Individual containers may also be encased in protective bunding and liquids should be held in totes where relevant, to prevent leakage or inundation.	Protective storage containers and areas reduce the risk of a chemical or hydrocarbon spill by lowering the likelihood of the container being breeched in the event of an accident resulting in impact. This reduces the risk of harm to personnel and pollution of ground or seawater.
Maintenance programs for all equipment	The hydrocarbon exploration and production lifecycle involves the use of many pieces of complex equipment, including: cranes and lifting equipment, drilling machinery, combustion engines, pumping equipment and pipelines. Frequent maintenance sessions may be performed on all equipment as part of an organised program, to check for faults and ensure that they are fit for purpose on a regular basis.	The implementation of maintenance programs ensures that equipment is fit for purpose and reduces the risk of important equipment failures, which can cause a multitude of negative effects.
Use of low hazard/risk chemicals and avoided use of high risk chemicals	Chemicals are used in several stages of the exploration and production lifecycle. Accidental (or planned) discharge of these substances to the ocean or ground is likely, particularly those which are injected into the well such as completion fluid or surfactants. Through regulation, the use of low hazard chemicals can be promoted and the use of high hazard chemicals prohibited or limited. For example, the OSPAR list of substances that ‘Pose little or no risk' to the environment (PLONOR) (OSPAR, 2012b) or under the "zero discharge principle" for the HELCOM region which requires cessation of discharges of all	The use of low hazard/risk chemicals and avoided use of high hazard/risk chemicals reduces the environmental damage caused by the accidental discharge to seawater or ground of chemicals used in the exploration and production process.

	"black" and "red" listed chemicals under the Baltic Sea Action Plan. Under the Barcelona Convention, discharge of harmful or noxious substances is either prohibited (Annex I) or requires a permit (Annex II); development of guidelines specifying the limitations or prohibitions for use of chemicals has been recommended. The REACH and CLP Regulations will also significantly affect choice/use of chemicals across Europe. However, there remain differences in approach amongst Member States in terms of chemical selection/substitution (Chemical Watch, 2014).	
Blow-out preventer	Subterranean hydrocarbon fields are held under high pressure by forces in the earth's crust. When these fields are penetrated by a well, the force must be controlled to ensure that well fluids are contained during production. Ablow-out preventer is a piece of equipment which acts as an emergency system to ensure that in the event of a failure of primary well control systems, over pressurisation does not result in a loss of containment of well fluids(a 'blowout').	A blowout can cause devastating environmental damage, as huge quantities of hydrocarbons are leaked into the surrounding ecosystems. A blow-out preventer prevents a loss of well fluids, should the primary well control systems fail.
Valve systems (SSIVs, X-mas trees, choke and kill):	Offshore and onshore rigs use many pipelines to transport chemicals and hydrocarbons. If these become damage, the fluids may be lost either to the surrounding ocean or to ground and groundwater, resulting in ecological harm. Valve systems such as subsea isolation valves (SSIV), Christmas tree values and choke and kills values can be used to shut off sections of piping. This ensures that if a pipeline is ruptured or leaking, the spillage can be contained.	Valve systems in piping reduce the quantity of fluids leaked to the surroundings in the event of a leakage or rupture. This reduces the pollution of land, groundwater and sea caused by such an event.
Well pressure monitoring	Alongside the use of a blow-out preventer to contain well fluids in the event of a loss of pressure control, monitoring technology may be employed to keep track of pressure within the well. This record of well pressure can be viewed in real-time, to enable personnel to take appropriate precautions to reduce well pressure when it is deemed to be dangerous.	Well pressure monitoring systems allow operators to be aware of when well pressure is at dangerous levels and take actions to reduce the risk of a blow-out or leakage, which cause significant environmental damage.
Emergency plans	Alongside the use of other measures to control accidental chemical or hydrocarbon releases, emergency plans may be put in place for personnel operating on the hydrocarbon site. These plans cover the clean-up procedures to take in the event of a spill. For more extreme spills (Tier III) they can also include plans for oil spill modelling, the training of specialist spill response operators and the contracting of assistance from specialist oil spill contractors.	Emergency plans allow personnel to be prepared to cope with chemical or oil spills when they occur. This ensures that clean up procedures are followed promptly and efficiently, and environmental damage from the spill is minimised.
Quick release valves for fuel off-take	Decanting and hose operations are used for the offtake of fuel and other fluids from storage tanks on the hydrocarbon site. Quick release valves may be fitted to the tanks. These allow pipelines or hoses to be remotely detach once transfer is complete, thus reducing the chance of a spillage of excess fluid.	Quick release valves reduce the amount of fluid spilt during off-take. This decreases the environmental damage caused by spills.
Flare tip design (enclosed flares) for gas flaring	In order to reduce air quality impacts and greenhouse gas emissions from gas released by a hydrocarbon field that cannot be processed, a proportion is continuously combusted in either an open air or enclosed system, known as flaring. Generally, open flares are inexpensive and relatively simple, but achieve poor emissions compared to enclosed flares, due to their lower combustion temperatures and shorter residence times. However, there are site specific factors (composition of hydrocarbon gas, noise considerations, etc.) which determine whether an open or enclosed flare is more suitable (Encyclopedia, n.d.). Flaring is also used as a safety precaution to control pressure build ups from gas in the well. BAT (best available techniques) may be used for the flare tip design. This ensure that the	Implementing BAT technology for flare tip design reduces the amount of air pollutants and CO_2 emitted to the atmosphere from gas flaring.

	efficiency of the combustion is as high as possible and reduces the emissions to air of pollutants such as NOx and smoke to the lowest levels that current technology allows.	
Controlled fall-pipe for rock dumping	Rock dumping refers to the use of rocks either to secure offshore hydrocarbon platforms to the seabed or as part of the decommissioning procedure for an onshore or offshore site. Specially designed vessels or vehicles maybe used to carry out the rock dumping, which are fitted with.	The use of controlled fall-pipes reduces the harm caused to surrounding habitats by the rock dumping process by ensuring that it is carried out accurately.
Leak detection and repair programmes	During the production, processing and handling of natural gas, accidental emissions to the atmosphere may occur. Methane and other trace chemicals in natural gas contribute to climate change and deteriorate air quality. Leak detection systems, combined with trained repair personnel and equipment can be used to reduce the amount of gas lost due to leakage.	Implementing leak detection systems and repair programmes reduces the amount of natural gas lost to leakage. This reduces contributions to climate change and air pollution.
Process design to avoid for gas venting in production	During natural gas production, gas may be vented in either a planned manner as part of the process, or an unplanned manner to control pressure for safety reasons. The production process can be designed by engineers to minimise the need for gas venting, either planned or unplanned.	Efficient process design of the natural gas production process reduces the amount of natural gas vented to the atmosphere and hence reduces harmful contributions to local air quality and climate change.
Treatment and analysis of discharged water	Sand and water are often produced from a hydrocarbon well alongside oil and gas. These contain residual hydrocarbons, production chemicals and reservoir contaminants. Systems may be installed to analyse and monitor the amount of pollutants in produced water (PW), and it may be treated before it is discharged in order to reduce the amount of contaminants it contains.	The treatment and analysis of water produced from the well reduces the amount of oil and other harmful pollutants emitted to surrounding ecosystems when the water is discharged.
Design and management of systems for cooling	Onshore production processes commonly utilise HVAC systems that contain ozone depleting substances (ODS). Accidental release of these substances contributes to climate change. Production processes may be designed and managed carefully to minimise the need for cooling, thus reducing the risk of an escape of ODS to the atmosphere.	Careful design and management of systems for cooling in onshore hydrocarbon production and exploration reduce the chance that ODS are emitted to the atmosphere, which contribute to global warming.
Ongoing monitoring of site post closure for issues	After hydrocarbon production is no longer economically viable, a site is decommissioned. Discarded drill cuttings and other remnants are piled up and the well bore is sealed. The presence of the pile can interfere with local habitats and leachate from the cuttings may cause pollution. Additionally, the wellbore can leak. The well bore and pile can be monitored periodically after the site closure to ensure that pollution levels and habitat damage are not high enough to require further intervention	By implementing ongoing monitoring of hydrocarbon production and exploration sites post closure, operators are able to intervene to address high levels of pollution or habitat damaged that may be being caused by the site remnants.
Environmental planning for geophysical testing	Geophysical testing and seismic surveys are used frequently in the onshore exploration process, to analyse rock formations and identify potential hydrocarbon reserves. Environmental planning may be carried out prior to conducting these surveys, so that tests are adapted to account for seasonality of migrating birds and fauna breeding seasons, which may be disturbed by seismic activities.	Environmental planning during the geophysical testing phase of hydrocarbon exploration reduces the disturbance caused to fauna and birdlife by onshore seismic activities by ensuring that surveys are not conducted during breeding or migration seasons.

BAT seismic equipment	Seismic equipment is used in the surveying stage of offshore and onshore hydrocarbon exploration. BAT (Best Available Technique) seismic technologies may be used to carry out geophysical testing. This ensures that the intrusion of seismic practices on local ecosystems is kept to the lowest levels achievable by current technologies.	Using BAT seismic equipment in the surveying phase of hydrocarbon exploration ensure that the disturbances to wildlife caused by geophysical testing are as low as technologically possible.
Environmental planning	Environmental planning involves careful consideration of the environmental impacts of activities, so that they may be minimised. This includes planning transportation routes, utilising good construction practices, implementing a waste management plan, minimising landtake of sites and establishing of baseline environmental aspect conditions which can be used to review potential impact on environment. Many stages of the onshore exploration and production lifecycle can be subjected to environmental planning, including: the mobilisation of drill rig and equipment, well rig construction, drilling of the well and decommissioning of the site.	Comprehensive environmental planning ensures that the environmental damage caused by many stages of the onshore exploration and production lifecycle are controlled and minimised where possible.
Noise abatement measures	The equipment used to drill hydrocarbon wells generates high levels of noise during operation. This noise can disturb wildlife and humans in the vicinity of the drill site. Screening, known as noise barriers or sound walls, may be installed around the drill. These are made of absorptive material that mitigates the intensity of the sound, thus reducing the harm that it causes to nearby creatures.	Noise abatement measures such as sound walls mitigate the intensity of sound emitted from hydrocarbon well drilling equipment. This reduces the disturbance caused to humans and wildlife in the vicinity of the site by drilling.
Water resource planning	Enhanced recovery activities such as water flooding and water and gas injection can use large quantities of water. To minimise the impact this can have on the environment, careful planning can be undertaken to ensure water is not taken from areas or sources that are prone to depletion and impose time restrictions on surface water diversions.	The water injected into hydrocarbon wells is removed from the water cycle for a considerable period of time, which has the potential to result in a strain on local freshwater resources. Through careful planning, the risk of water depletion and its associated negative impacts on the environment can be reduced or avoided.

The following findings resulted from a meta-analysis of risk characteristics in terms of the likelihood and the consequence of environmental aspects, after applying expected mitigation measures, in each stage. The results are presented below.

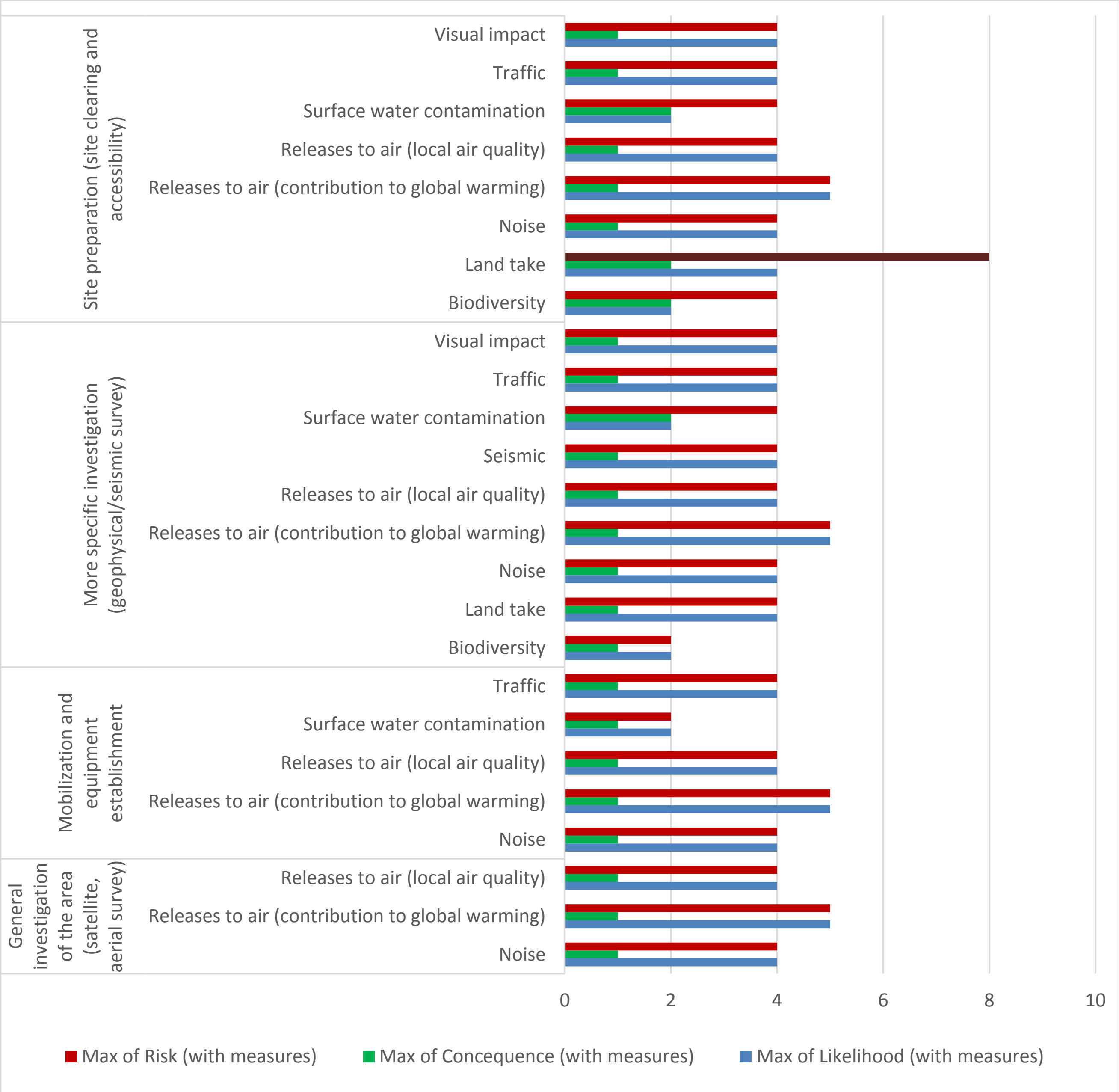


Figure 4.2.2.2: A meta-analysis for stage 1, with the expected mitigation measures. The connection between risk, consequence and likelihood for every impact (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

According to *Figure* 4.2.2.2, during 1st stage the risk exceeds the average, regarding land take, during the site preparation process.

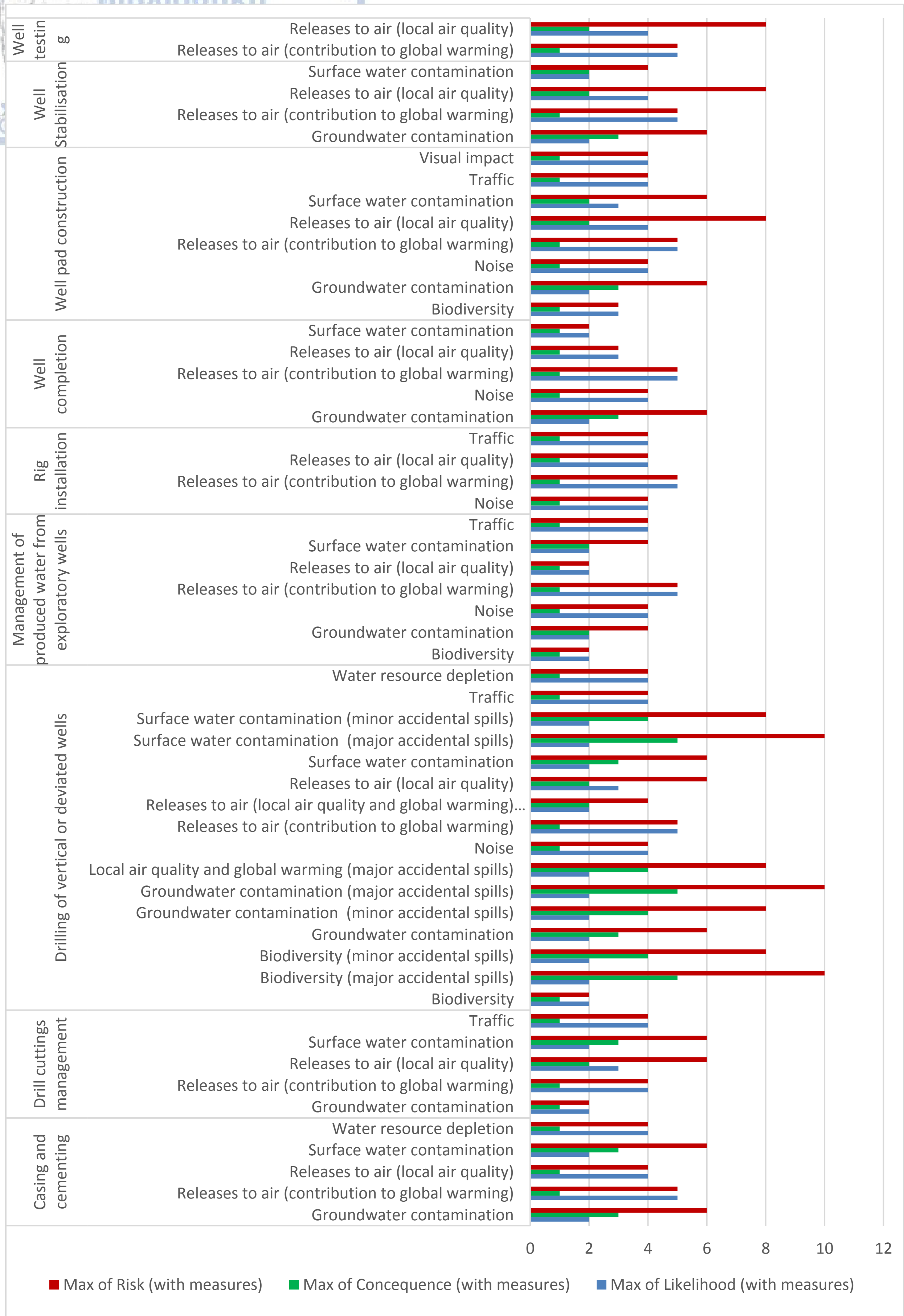


Figure 4.2.2.3: A meta-analysis for stage 2, with the expected mitigation measures. The connection between risk, consequence and likelihood for every impact (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

On the contrary, as it was anticipated, the values of *Figure 4.2.2.3* are higher than those of the first stage, since the petroleum activities are more difficult and complex. It must be noted that in case of an incident (both minor and major), all the values appear to be escalated, reaching to its maximum value. For example, the consequence of the impacts rises when it comes to the contamination of air and ground and the changes in biodiversity. Since stage 3 includes also activities with great environmental intervention, the values of *Figure 4.2.2.4* present the same fluctuation.

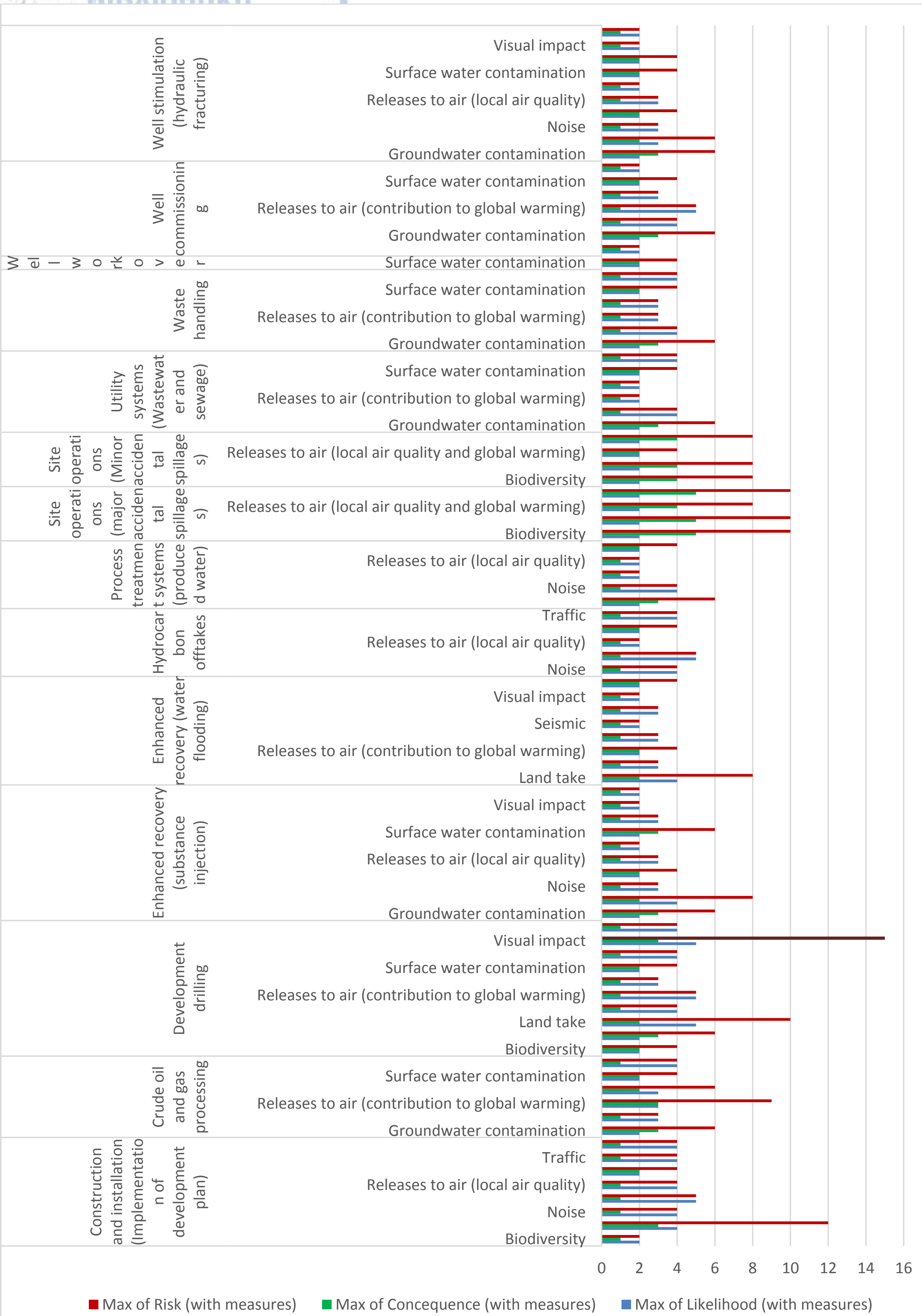


Figure 4.2.2.4: A meta-analysis for stage 3, with the expected mitigation measures. The connection between risk, consequence and likelihood for every impact (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

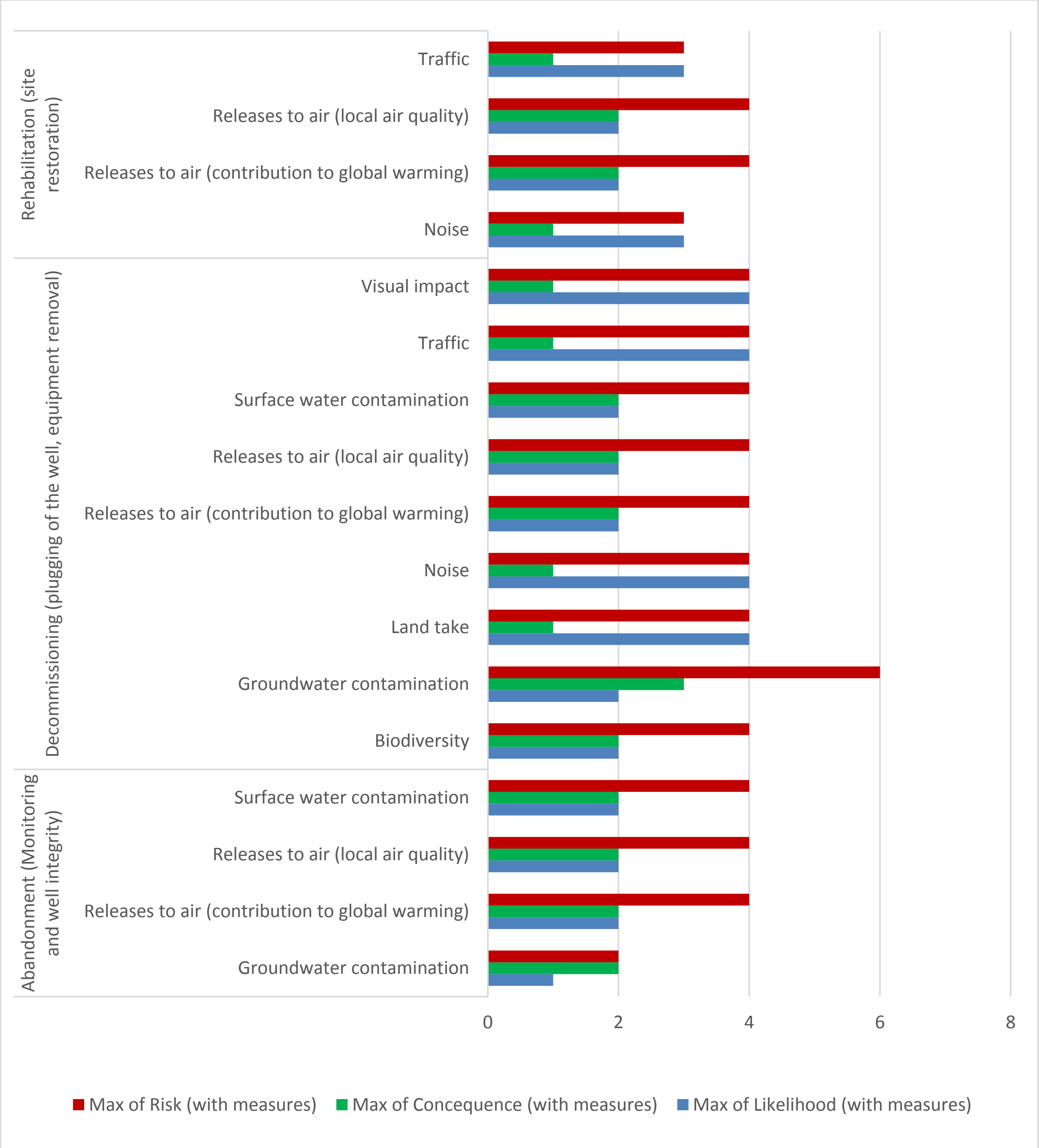


Figure 4.2.2.5: A meta-analysis for stage 4, with the expected mitigation measures. The connection between risk, consequence and likelihood for every impact (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

In accordance with *Figure 4.2.2.5*, all risk values apart from one (the risk of ground contamination) are below the average (#4).

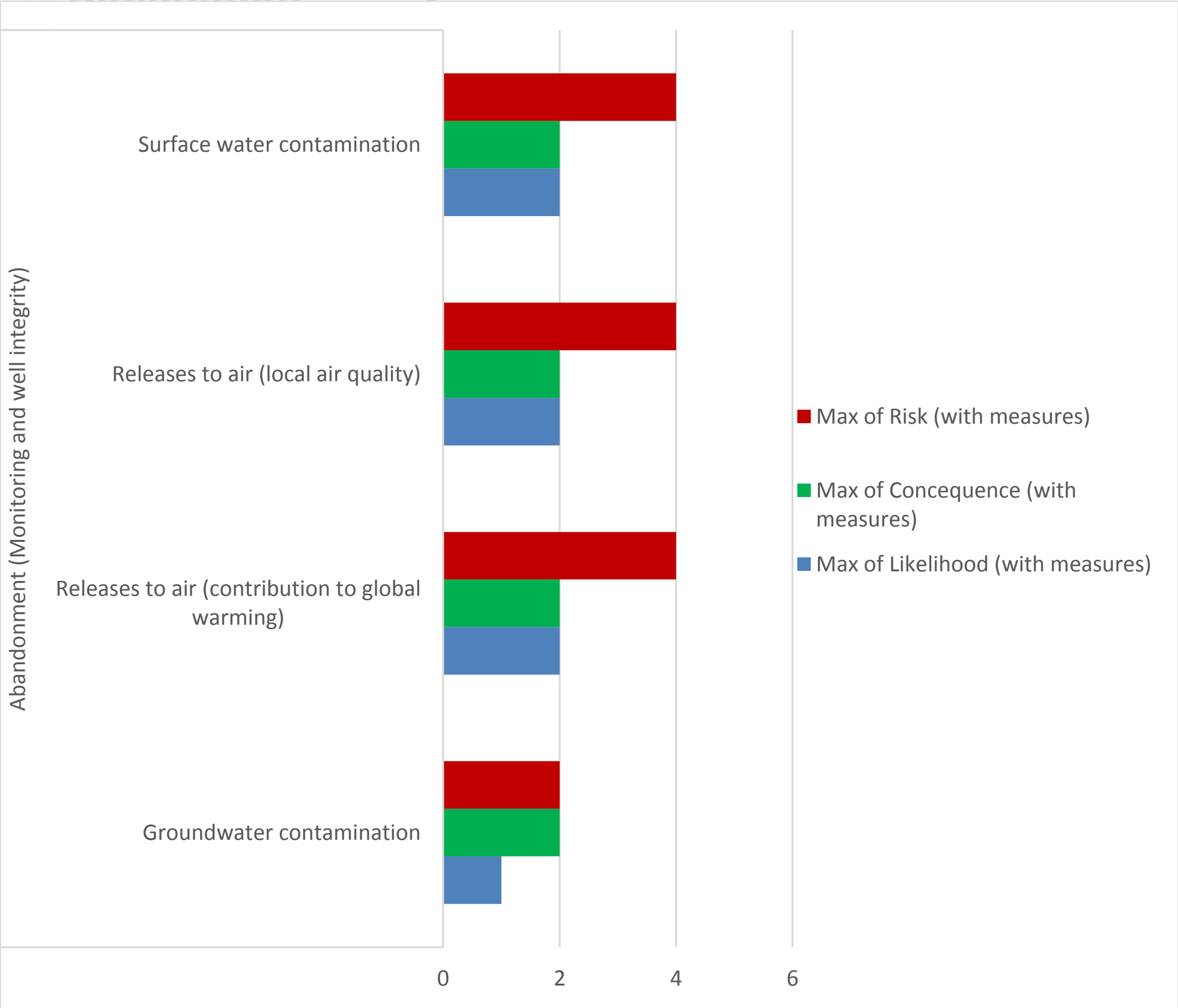


Figure 4.2.2.6: A meta-analysis for stage 5, with the expected mitigation measures. The connection between risk, consequence and likelihood for every impact (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

Lastly, since stage 5 is the stage of monitoring and maintenance, the values present the lowest values in comparison with the rest of the stages. In an event of causing releases to air or surface contamination the risk is high.

To conclude, with the implementation of the measures, the majority of the values of all three values (risk, consequence and likelihood) appear to be diminished and approach more average values.

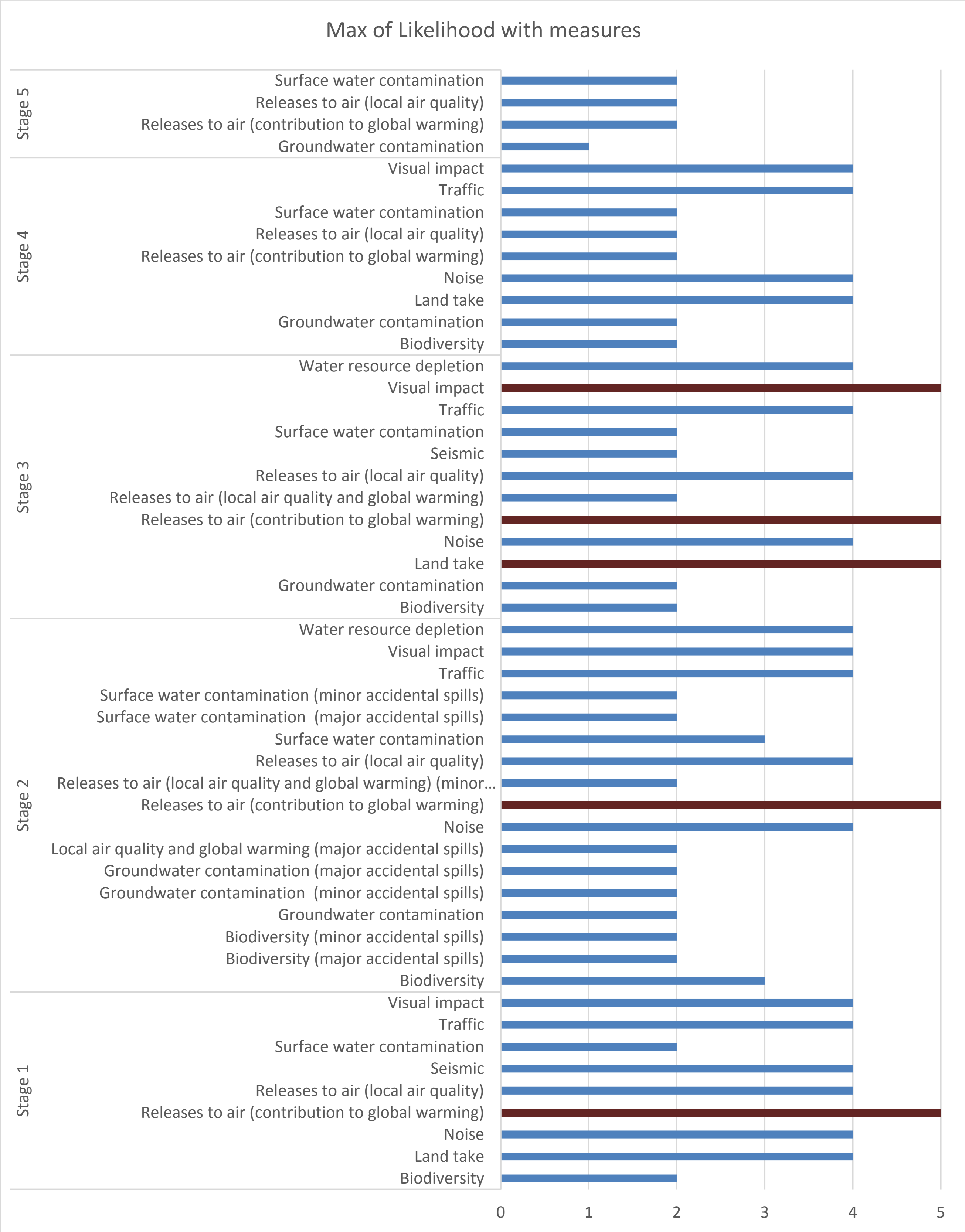


Figure 4.2.2.7: A meta-analysis of every impact in terms of likelihood (max of likelihood) for each stage, with the expected mitigation measures (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

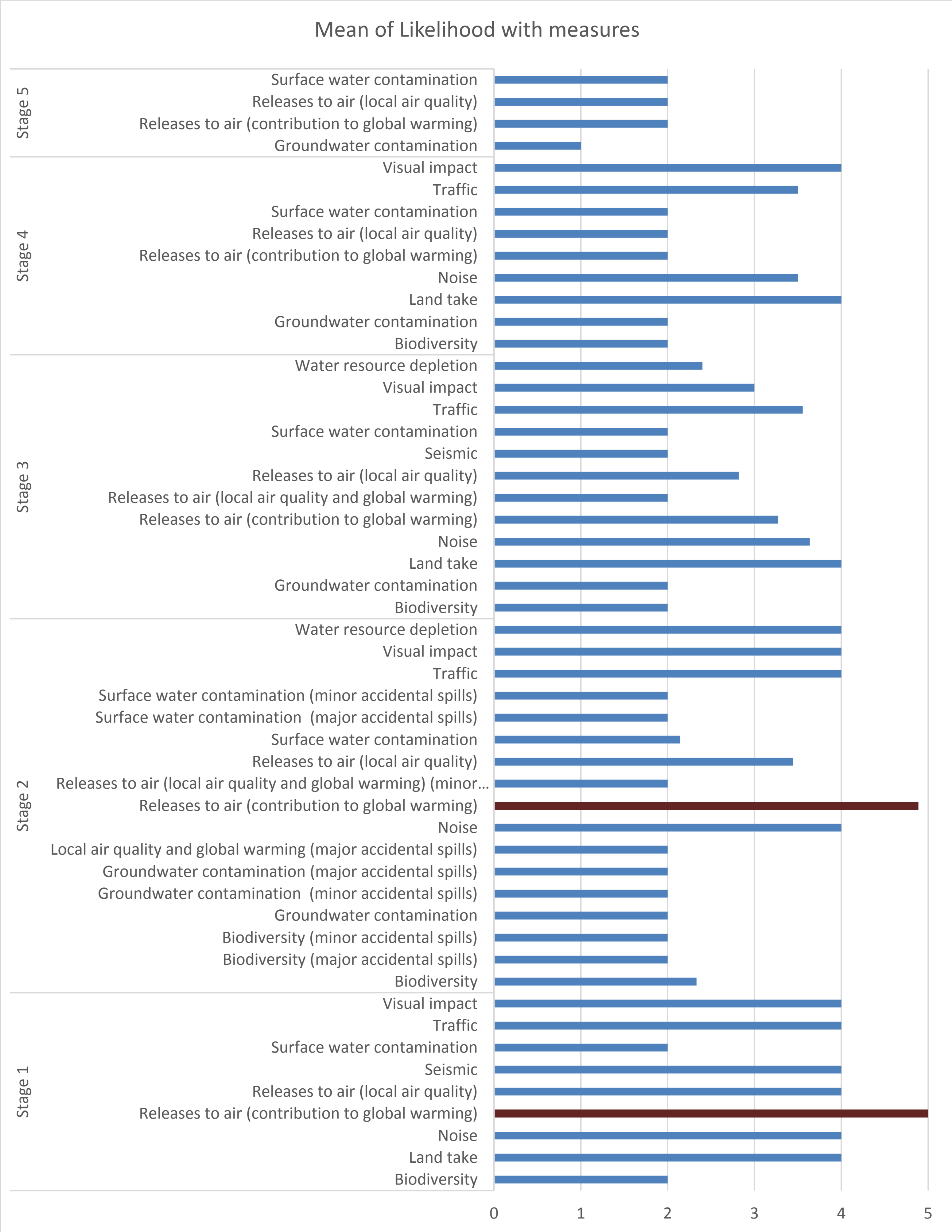


Figure 4.2.2.8: A meta-analysis of every impact in terms of likelihood (mean of likelihood) for each stage, with the expected mitigation measures (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

In accordance with the *Figure 4.2.2.7*, the three first stages of petroleum activity carry the greatest possibility of provoking an impact, with emphasis on the 2nd and the 3rd. Despite the implementation of the measures, the values seem high up to extremely high, regarding the releases to air, the visual impact and the land take. The results are high because the figure is based only on the maximum value of likelihood occurred in at least one process of each stage. It needs to be mentioned that, the impact "releases to air" doesn't seem to be influenced or minimized by the implementation of measures.

In correspondence with what was analyzed above, *Figure 4.2.2.8* demonstrates the mean rates of likelihood of all processes in each stage. All the values seem to have been decreased besides the releases to air, of stage 1 and 2, which shows a strong tendency of occurring.

Regarding the difference between the values of the maximum and average likelihood, there are some processes in the petroleum activity, which are linked with the highest (maximum) possibility of provoking a significant impact. In particular, in stage 1, the only impact that enters the red zone is the "releases to air-contribution to global warming". The processes that influence this value are all the processes of stage 1 (**site preparation**, **more specific investigation**, **mobilization and equipment establishment** and **general investigation**). Considering stage 2, the only impact that enters the red zone is again the "releases to air-contribution to global warming". The processes that influence this value are pretty much all the processes of stage 2. More specific, "**Well testing**", "**Well stabilization**", "**Well pad construction**", "**Well completion**", "**Rig installation**", "**Management of produced water**", "**Drilling of vertical or deviated wells**" and "**Casing and cementing**". Since the likelihood of this impact increases by the realization of all the processes, then it was anticipated the no declining of values regarding the average values. In other words, when the value it's in maximum pick in more than one process, then the average value of likelihood of provoking a significant impact will maintain high values.

Lastly, in stage 3 the processes that influence the max of likelihood values are:

- The "**Well commissioning**", the "**Hydrocarbon offtakes**", the "**Development drilling**", and the "**Construction and installation**", which increase the value of the contribution to global warming.
- The "**Development drilling**", which influences the land take, the releases to air (contribution to global warming), and the visual impact.

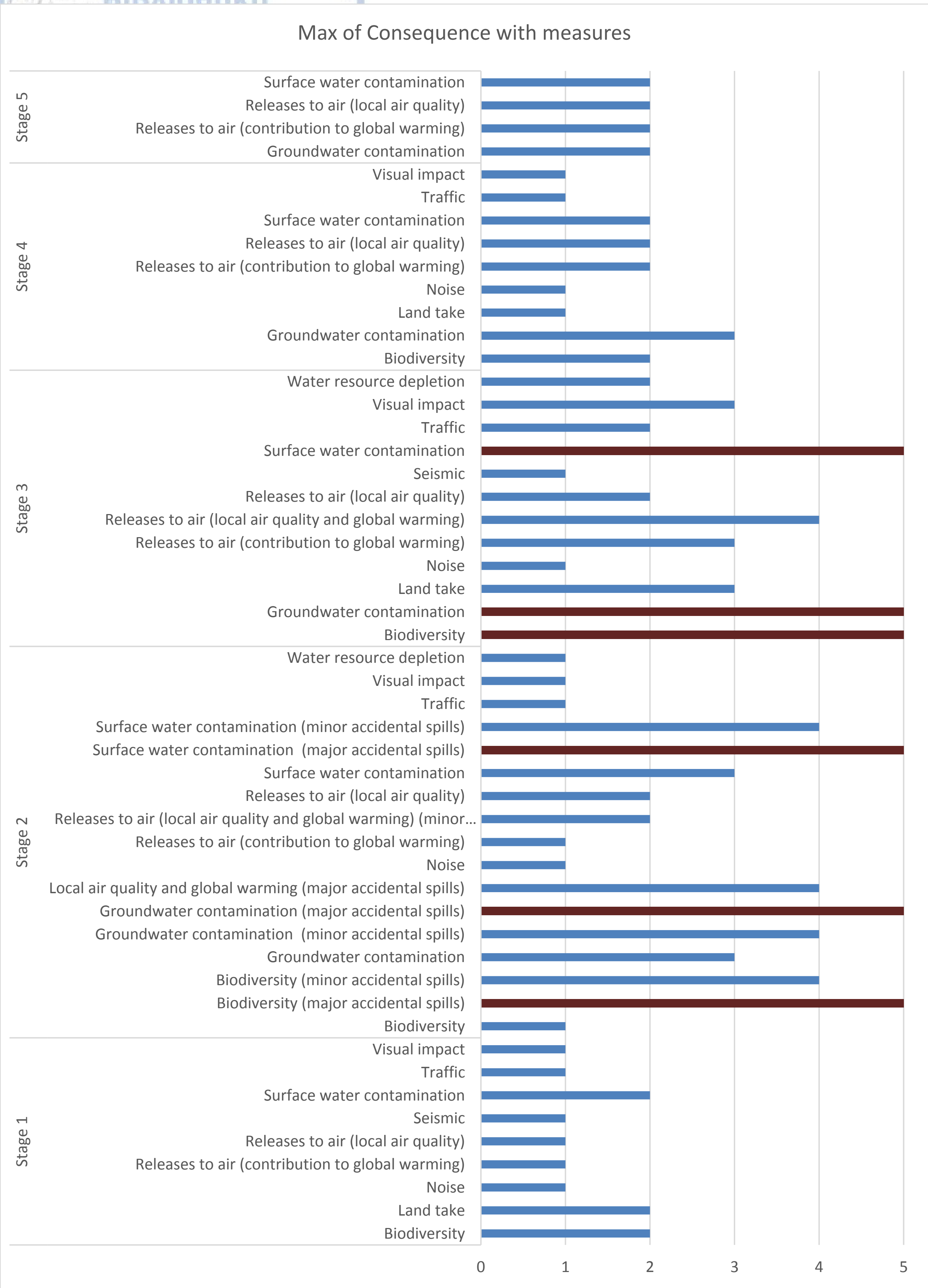


Figure 4.2.2.9: A meta-analysis of every impact in terms of consequence (max of consequence) for each stage, with the expected mitigation measures (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

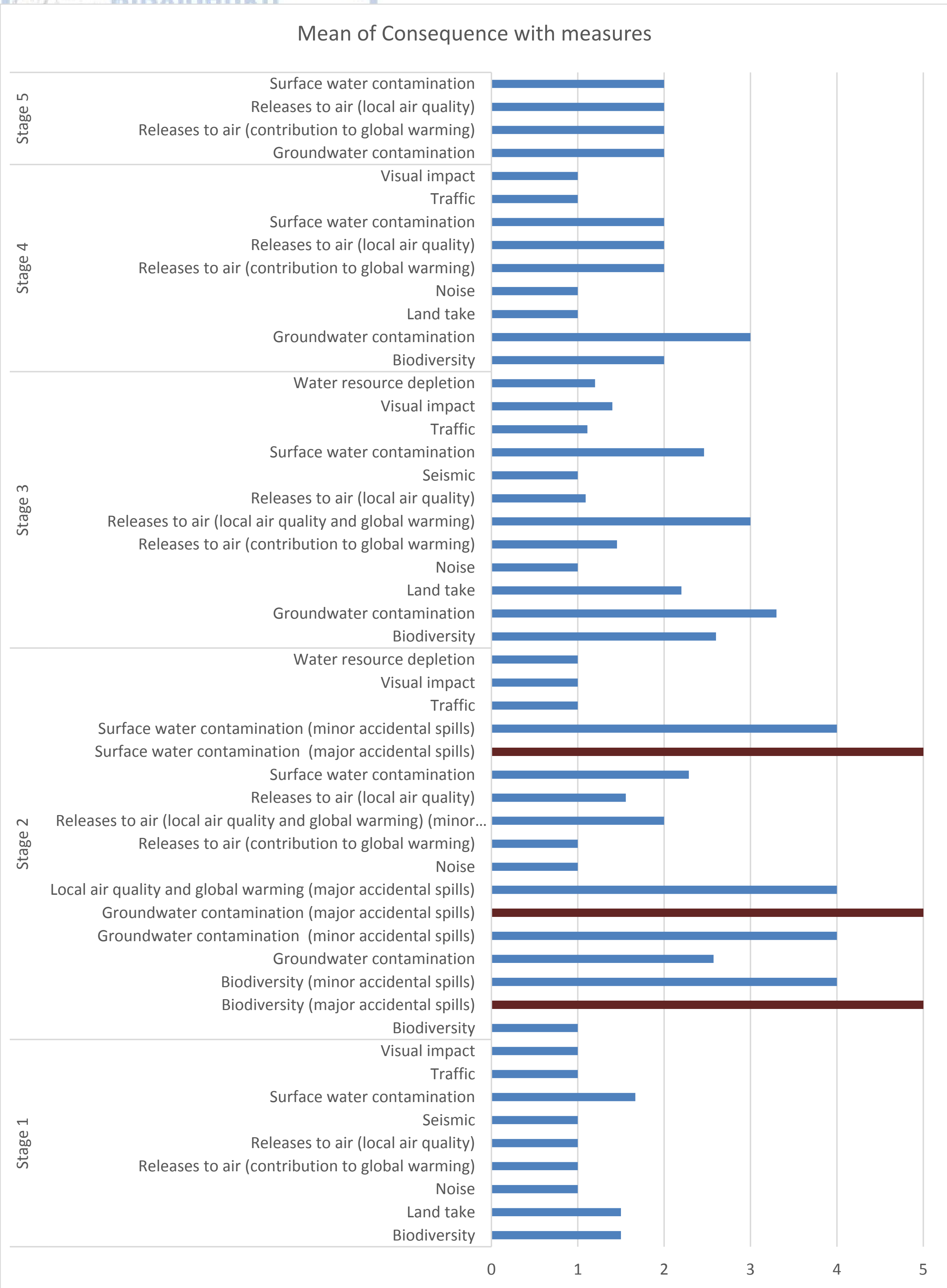


Figure 4.2.2.10: A meta-analysis of every impact in terms of consequence (mean of consequence) for each stage, with the expected mitigation measures (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

According to *Figure* 4.2.2.9, only the 2nd and 3rd stage in petroleum activity carry the greatest consequence. Specifically, during these stages, the impacts with the greatest consequence are: contamination (surface water and groundwater) and biodiversity. In any case, the consequence depends on what petroleum activities are executed and under which scale. For example, a large scale intervention to the environment will provoke greater consequences. This figure is based on the maximum values of consequence, which is why the values appear to be that high. However, in *Figure 4.2.2.10*, which demonstrates the mean values of consequence of all processes in each stage, the numbers are minimized, with the exception of a spill incident.

More specific, regarding the difference between the values of the maximum and the average consequence, there are some processes, which are linked with the highest (maximum) impact consequence. In other words, in stage 2, the process that influences and draws the consequence to its highest value (#5) is the "**Drilling of vertical or deviated wells**", which in case of a major spill increases the surface water contamination, the groundwater contamination and the biodiversity. Likewise, during stage 3, the process that affects the most the value of consequence is the "**Site operations**", which in case of a major spill increases to its peak the surface water contamination, the groundwater contamination and the biodiversity.

By all means, in case of a major incident during the process of drilling at stage 2, the average consequence maintains its maximum value, without dropping, while at stage 3, the average consequence seem to be off the red area, which means that the values managed to drop.

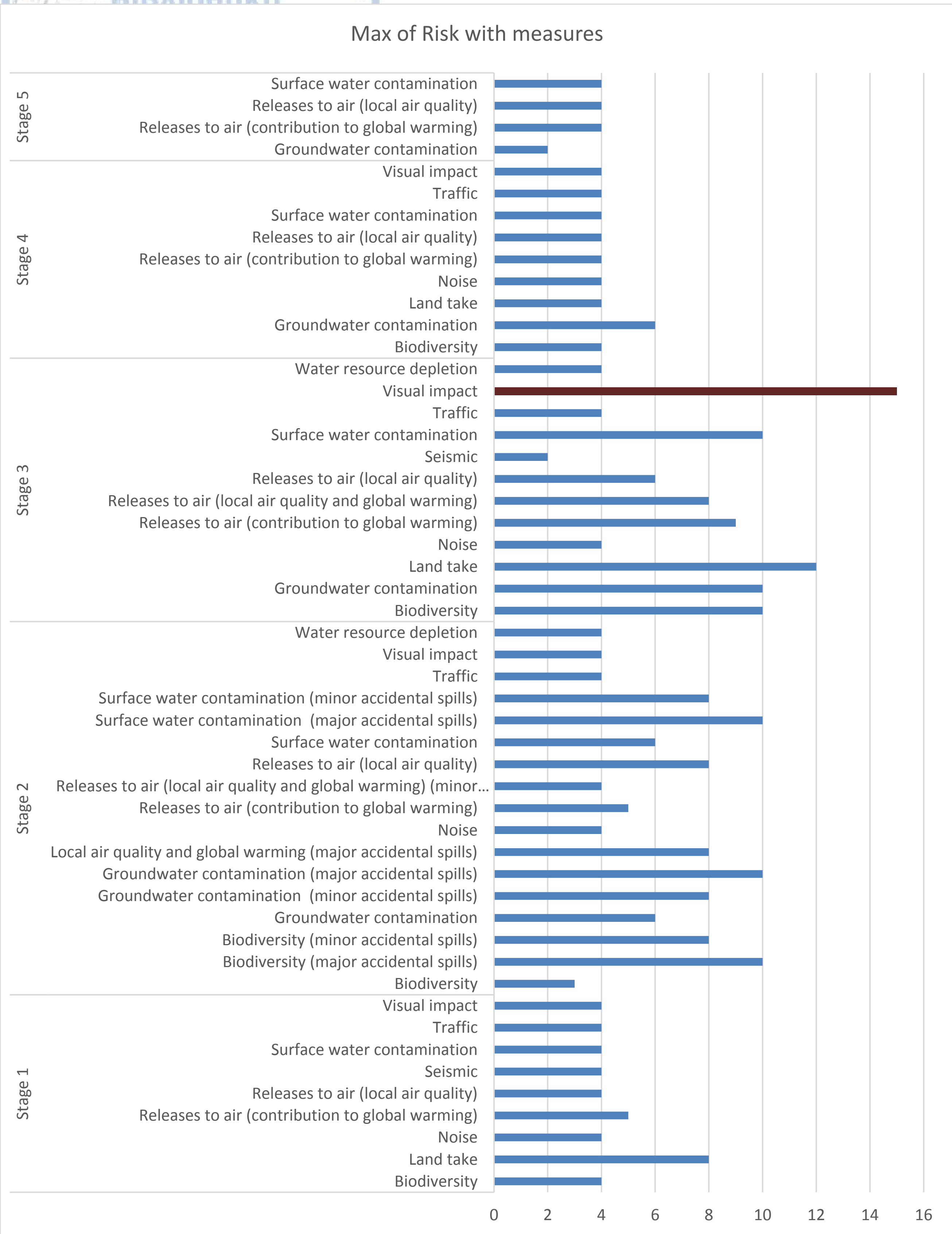


Figure 4.2.2.11: A meta-analysis of every impact in terms of risk (max of risk) for each stage, with the expected mitigation measures (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

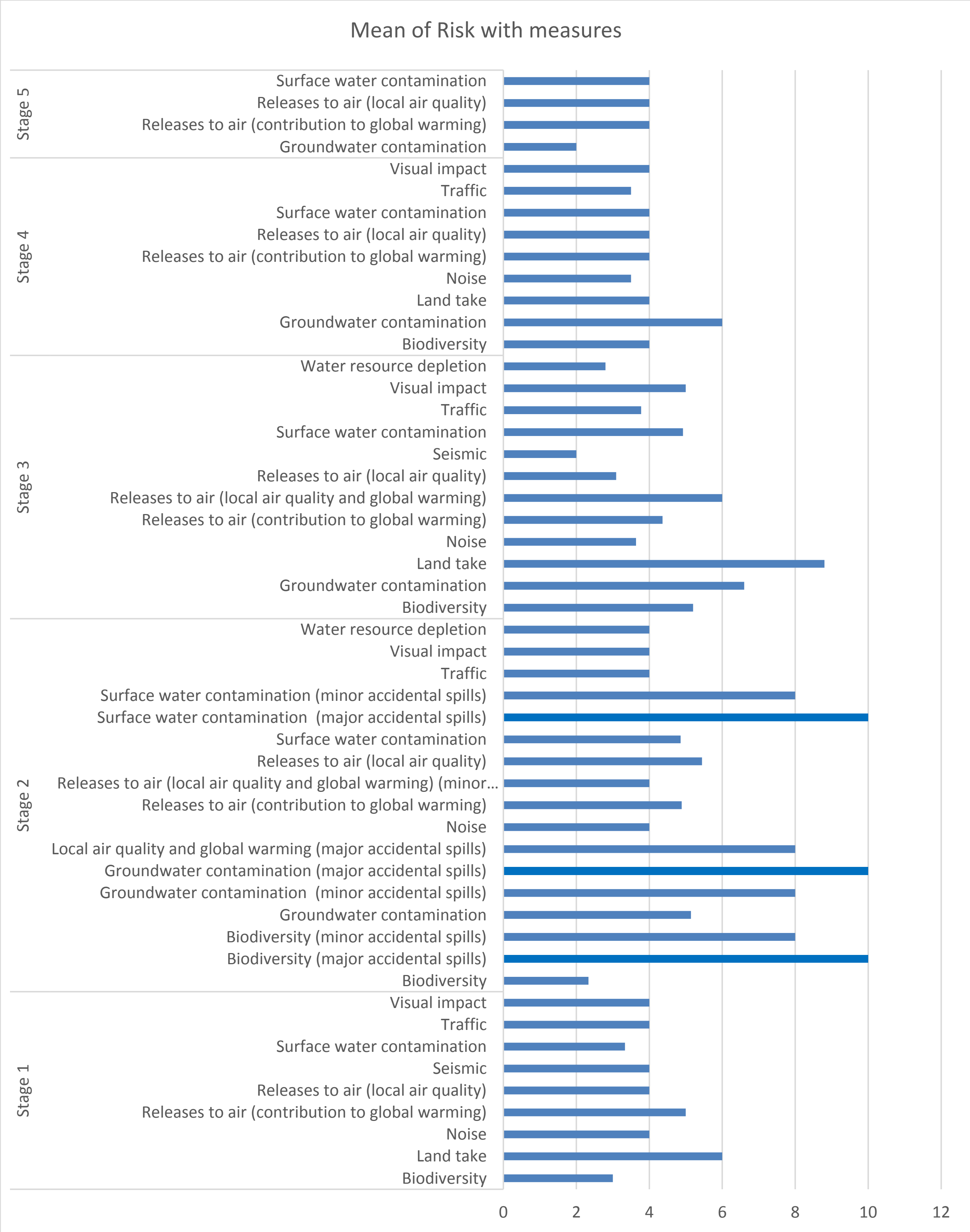


Figure 4.2.2.12: A meta-analysis of every impact in terms of risk (mean of risk) for each stage, with the expected mitigation measures (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

In accordance with *Figure 4*.2.2.11, which is based on the maximum values of risk, only in stage 3 the visual impact seam to enter the red zone (maximum risk). The results are high because the figure is based only on the maximum value of likelihood occurred in at least one process of each stage. As a conclusion it can be assumed that the implementation of the measures has helped to reduce the risk. *Figure 4*.2.2.12., appears to verify this conclusion, with the only difference that the values decreased, since the figure is in terms of the average values of risk of all processes in each stage.

Regarding the difference between the values of maximum and average risk, there are some processes, which affect to the full, the values of risk to increase. In particular, in stage 2, in case of a major spill, the process of "**Drilling of vertical deviated wells**", increases the values of surface water contamination, groundwater contamination and biodiversity to maximum. Additionally, in stage 3 the process that influences the risk values is the "**Site operations**", which in case of a major spill increases to its peak the surface water contamination, the groundwater contamination and the biodiversity. Moreover, during the process of the "**Development drilling**", the visual impact seems to enter the red zone.

Finally, the process that affects the most the risk value is the "**Drilling of vertical deviated wells**" process, due to the fact that even considering the average values, the risk of provoking surface water contamination, groundwater contamination and biodiversity remains to its maximum value.

Comparison of risk level with and without measures

The following figures have been created with the expectation to indicate the significance of the measures' implementation. Each figure is based only on one value and compares the values regarding the implementation or not of the measures. The results are demonstrated by stage.

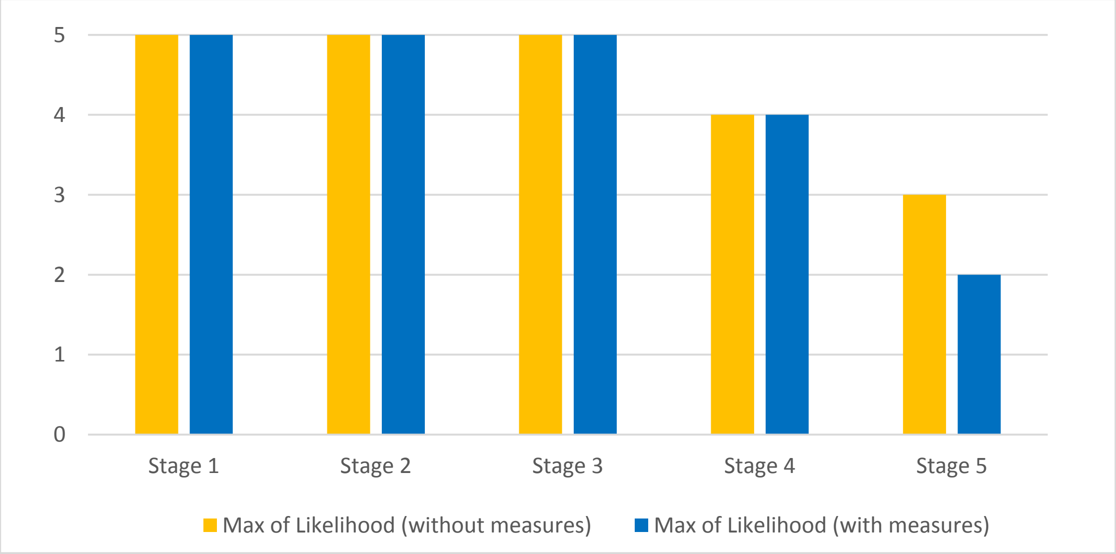


Figure 4.2.2.13: A meta-analysis of the maximum values of likelihood for each stage (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

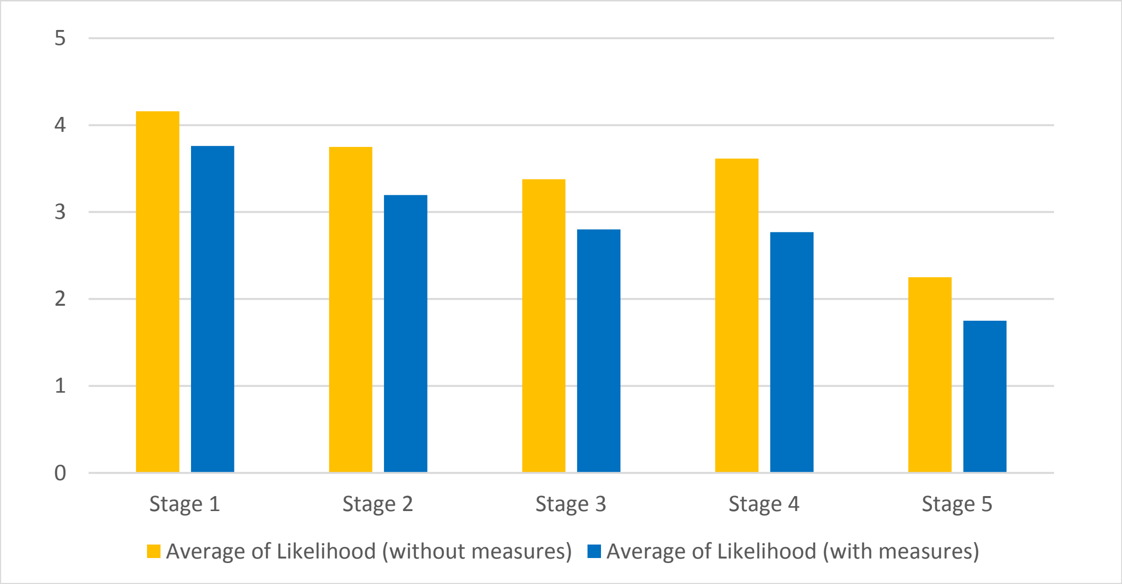


Figure 4.2.2.14: A meta-analysis of the average values of likelihood for each stage (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

Since the analysis was based on the maximum values of likelihood (*Figure 4.2.2.13*), the deviation between the likelihood with the measures and the likelihood without the measures is zero. Only at stage 5 there is a slight deviation, which is due to the simplicity of the activities of this stage. In other words, the likelihood of provoking an impact during stage 5 can be diminished after applying the measures. On the other hand, according to *Figure 4.2.2.14*, which presents the average values of likelihood the deviation increases. In every case, regarding always the severity and the simplicity of the processes of every stage, the likelihood of provoking an impact after the implementation of measures decreases.

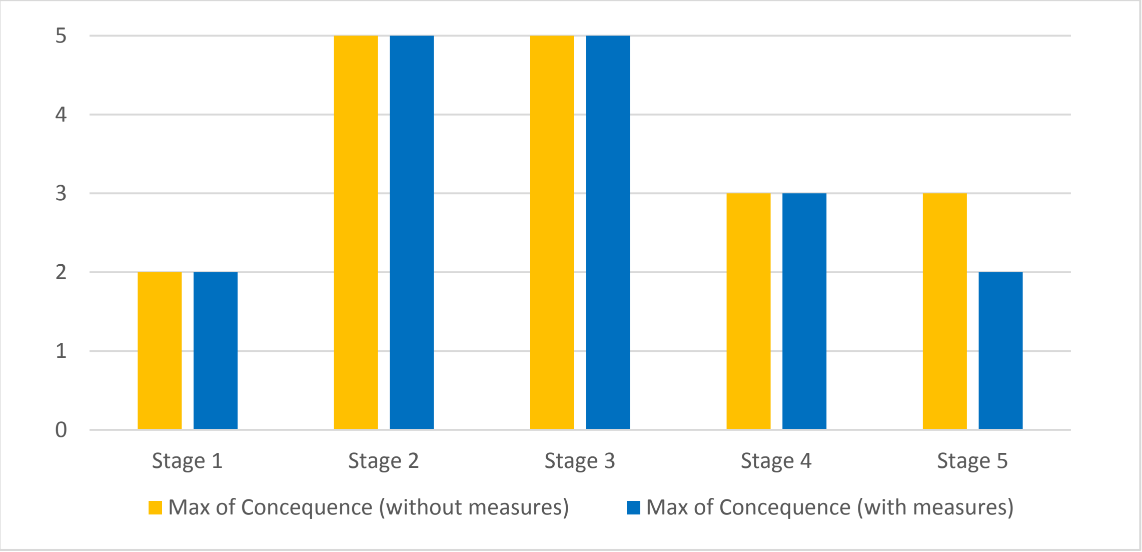


Figure 4.2.2.15: A meta-analysis of the maximum values of consequence for each stage (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

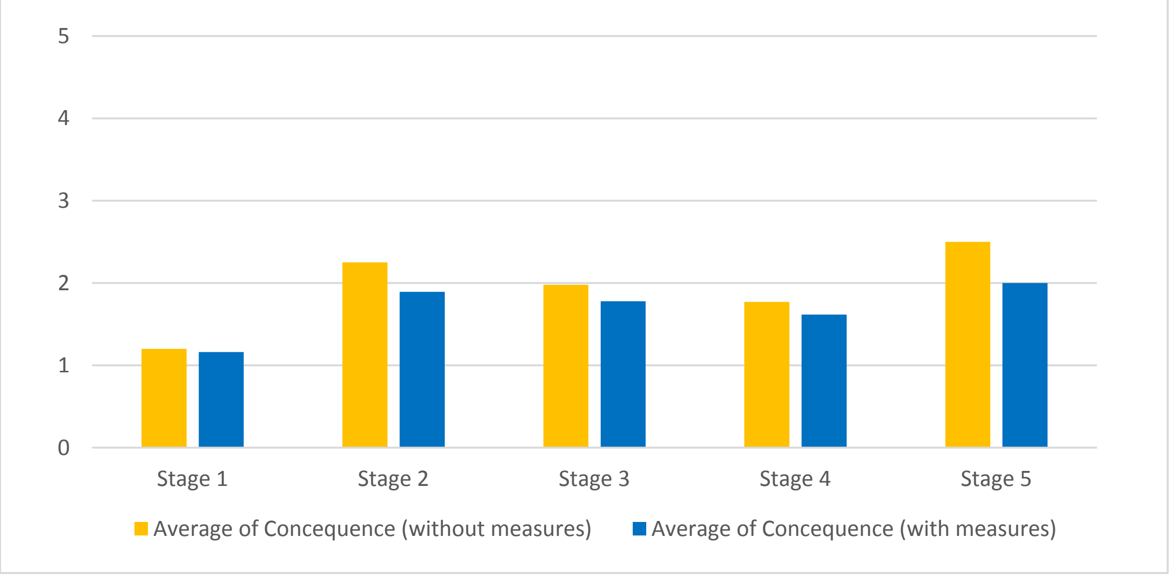


Figure 4.2.2.16: A meta-analysis of the average values of consequence for each stage (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

Furthermore, if we take under consideration the figures regarding the maximum and average values of consequence (*Figure 4.2.2.15* and *Figure 4.2.2.16*), it can be drawn the exact same conclusion as in likelihood.

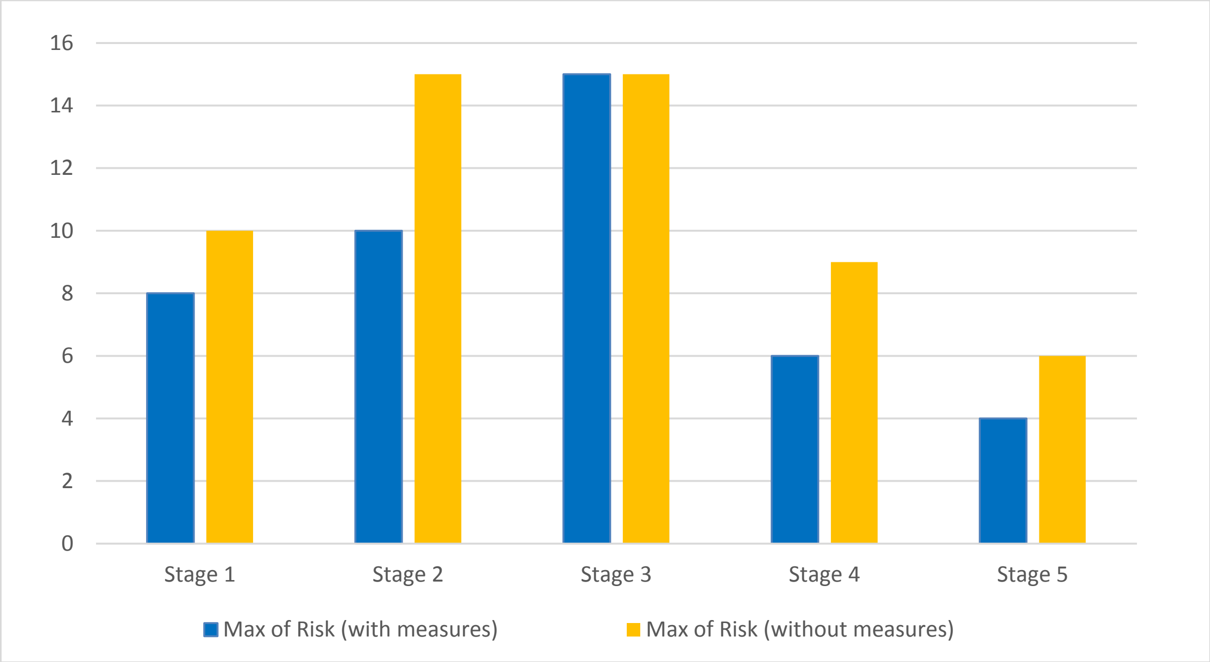


Figure 4.2.2.17: A meta-analysis of the maximum values of risk for each stage (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

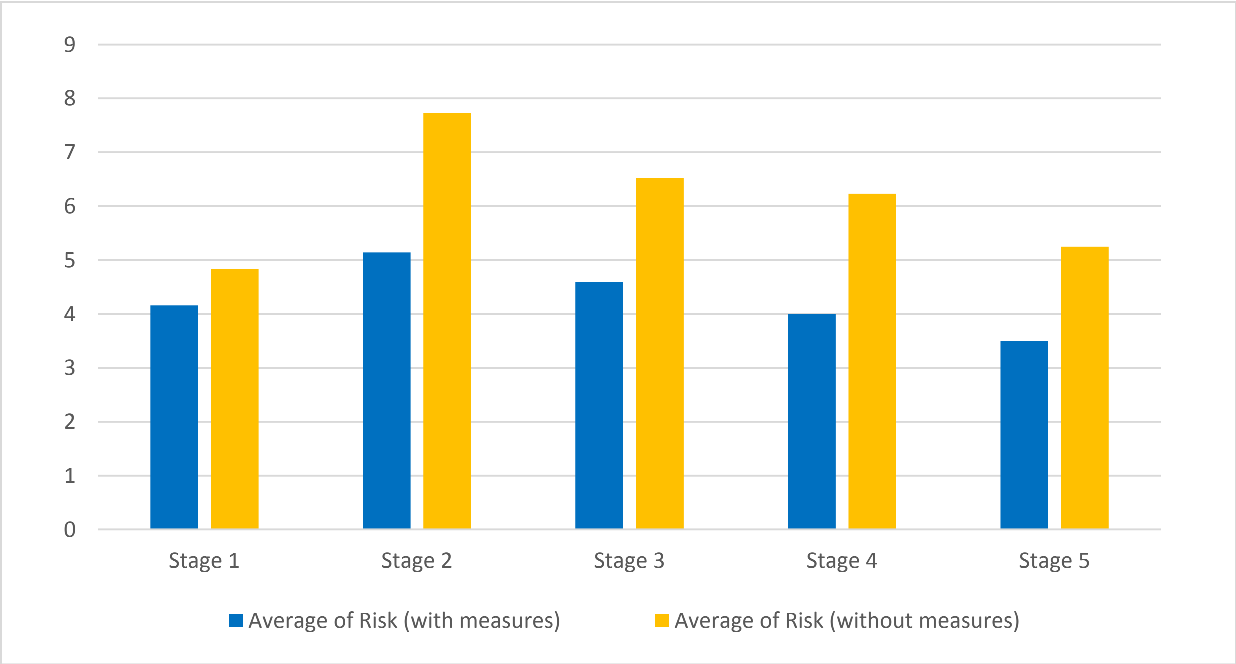


Figure 4.2.2.18: A meta-analysis of the average values of risk for each stage (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

According to *Figure 4.2.2.17*, which is based on the maximum values of risk, there is a decrease of the value of risk after applying the measures. Only in stage 3 the results are different, where the petroleum activities carry the greatest risk. Specifically, the visual impact of stage 3 will maintain its maximum value regardless the implementation of the measures. Lastly, the average values of risk present greater fall after the implementation of measures. In other words, if the measures are carried out, the (average) risk of an impact to happen can be decreased.

For the purpose of demonstrating the gradation of the risk, the following figure has been made in accordance with the process in petroleum industry, while the second figure is based on the type of impact.

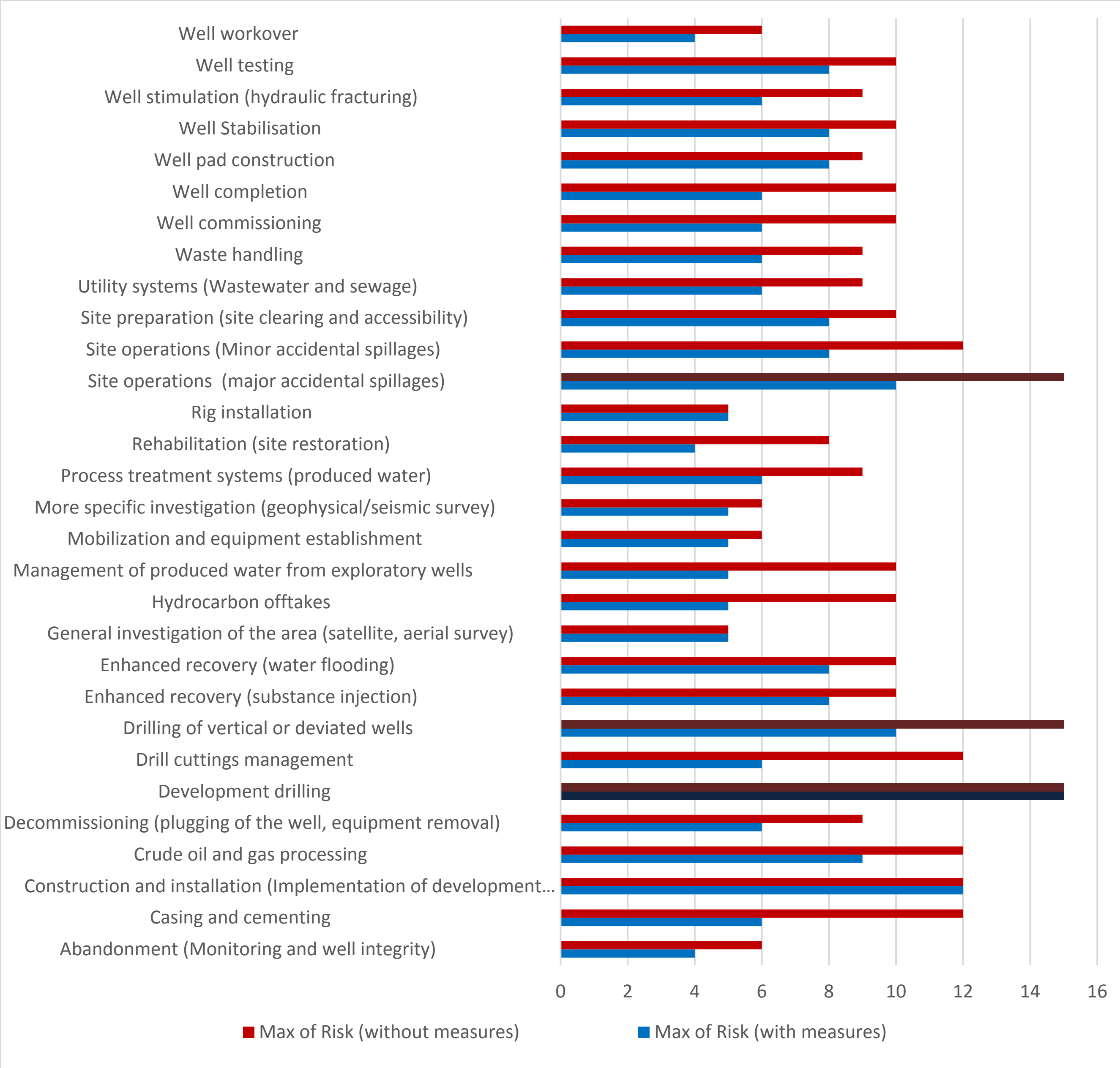


Figure 4.2.2.19: A meta-analysis of the maximum values of risk, regarding the process (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

To begin with, regarding *Figure 4.2.2.19*, there is a clear difference between the values of risk with the measures and without them. In general, after applying the measures the values of risk preserve their rates around the average. However, as it was commented previously, the risk depends on what activities are executed and under which scale. For this exact reason, during drilling the risk of provoking an impact is the maximum either with measures or not, since the drilling is one of the most hard and complicated processes of the petroleum activity. The same happens also in a case of an accidental major spill.

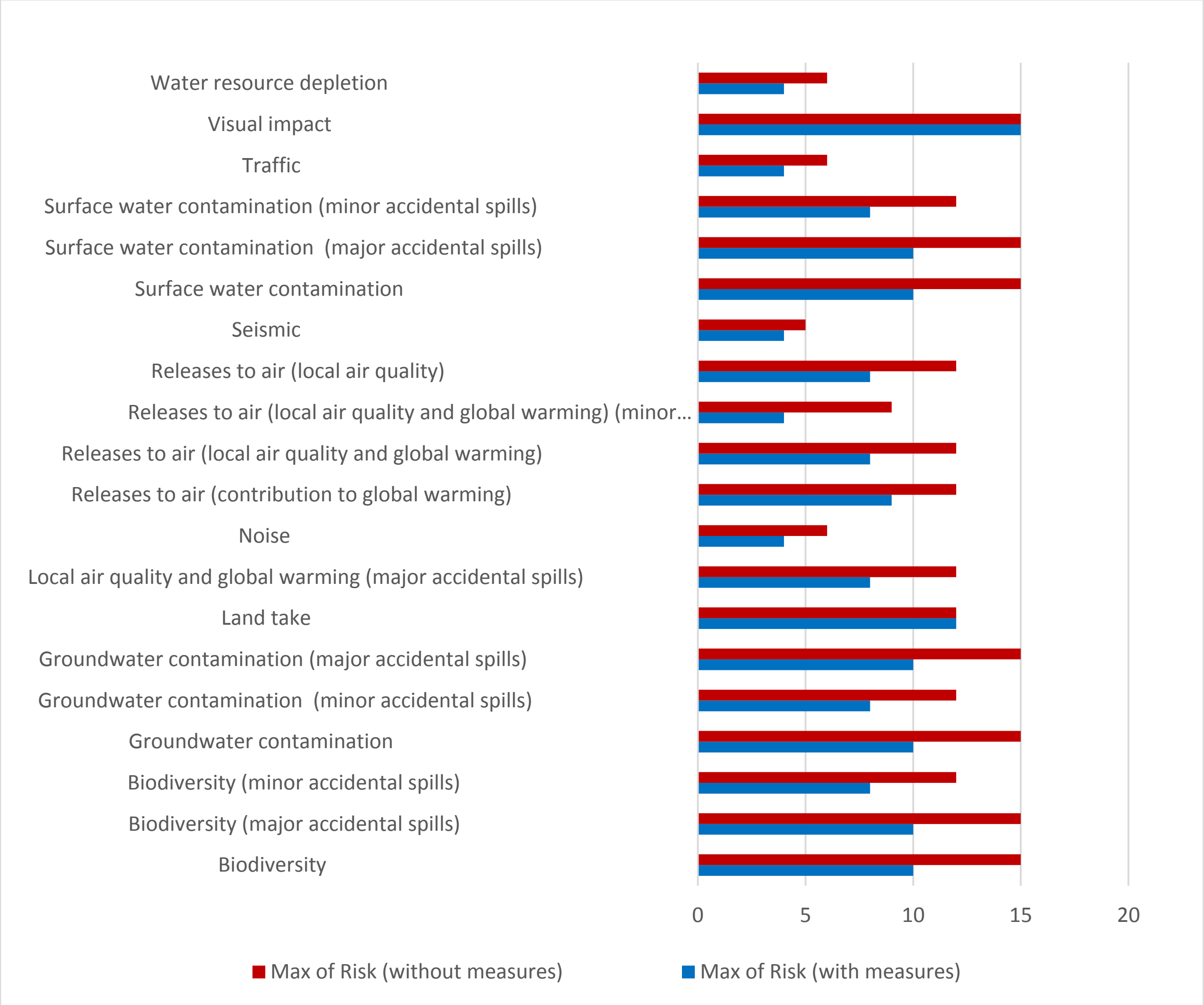


Figure 4.2.2.20: A meta-analysis of the maximum values of risk, regarding the impact (*Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

Regarding the impacts (*Figure 4.2.2.20*), there is also a difference between the risk without the implementation of measures and with it, except for the visual impact. This happens because even if there are taken precautions; the image of the environment will change, since all the processes are necessary to be done.

The following tables summarize the reduction in risk, consequences and likelihood after the implementation of measures. The analysis is given separately for each stage, impact and process.

Table 4.2.2.2: Percentages of risk reduction for each stage individually after the implementation of measures, *(Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

Stage		**Risk (no measures)**	**Risk (with measures)**	**Risk reduction (%)**
Stage 1	Mean	4.8	4.2	-14.0%
	N	25	25	
	Std. Deviation	1.3	1.1	
Stage 2	Mean	7.7	5.1	-33.5%
	N	56	56	
	Std. Deviation	3.4	2.0	
Stage 3	Mean	6.5	4.6	-29.6%
	N	90	90	
	Std. Deviation	3.4	2.5	
Stage 4	Mean	6.2	4.0	-35.8%
	N	13	13	
	Std. Deviation	1.8	.7	
Stage 5	Mean	5.3	3.5	-33.3%
	N	4	4	
	Std. Deviation	1.5	1.0	
Total	Mean	6.6	4.6	-29.9%
	N	188	188	
	Std. Deviation	3.2	2.1	

According to what was mentioned above, the stages with the greatest risk are: Firstly, the 2nd, the 3rd, the 4th, the 5th, and lastly the 1st. This conclusion can be verified by the above table, with the exception that the percentages appear slightly different due to the value deviation after and before applying the measures. In other words, when a petroleum process is less complicated, the effect of the implementation of the measures diminishes. This theory can be confirmed by the stage with the less complicated procedures, stage 1.

Table 4.2.2.3: Percentages of risk reduction for each impact individually after the implementation of measures, *(Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

Impact		Risk (no measures)	Risk (with measures)	Risk reduction (%)
Biodiversity	Mean	6.4	3.9	-38.6%
	N	11	11	
	Std. Deviation	3.8	2.7	
Biodiversity (major accidental spills)	Mean	15.0	10.0	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Biodiversity (minor accidental spills)	Mean	12.0	8.0	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Groundwater contamination	Mean	8.6	5.8	-32.5%
	N	19	19	
	Std. Deviation	2.6	1.8	
Groundwater contamination (minor accidental spills)	Mean	12.0	8.0	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Groundwater contamination (major accidental spills)	Mean	15.0	10.0	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Land take	Mean	9.0	7.5	-16.7%
	N	8.0	8.0	
	Std. Deviation	2.4	2.8	
Local air quality and global warming (major accidental spills)	Mean	12.0	8.0	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Noise	Mean	4.4	3.8	-14.4%
	N	22	22	
	Std. Deviation	.7	.4	
Releases to air (contribution to global warming)	Mean	7.1	4.6	-35.8%
	N	27	27	
	Std. Deviation	2.9	1.2	
Releases to air (local air quality and global warming)	Mean	10.5	6.0	-42.9%
	N	2	2	
	Std. Deviation	2.1	2.8	
Releases to air (local air quality and global warming) (minor accidental spills)	Mean	9.0	4.0	-55.6%
	N	1	1	
	Std. Deviation	.	.	
Releases to air (local air quality)	Mean	5.9	4.1	-30.6%
	N	27	27	
	Std. Deviation	2.6	1.8	
Seismic	Mean	2.8	2.5	-9.1%
	N	4	4	
	Std. Deviation	1.5	1.0	

Surface water contamination	Mean	7.8	4.6	-40.5%
	N	25	25	
	Std. Deviation	2.8	1.7	
Surface water contamination (major accidental spills)	Mean	15.0	10.0	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Surface water contamination (minor accidental spills)	Mean	12.0	8.0	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Traffic	Mean	4.5	3.8	-15.1%
	N	19	19	
	Std. Deviation	.7	.4	
Visual impact	Mean	5.0	4.6	-8.9%
	N	9	9	
	Std. Deviation	4.2	4.0	
Water resource depletion	Mean	4.0	3.1	-21.4%
	N	7	7	
	Std. Deviation	1.2	1.1	
Total	Mean	6.6	4.6	-29.9%
	N	188	188	
	Std. Deviation	3.2	2.1	

If all measures are taken under consideration, in case of a minor accidental spill, the risk of contamination the air is reduced to half. In a general aspect, when measures are applied, the risk of provoking a great impact is minimized. On the other hand, there are impacts, such as visual impact, noise, traffic or seismic impact that present a small percentage deviation after and before the implementation of measures. This happens due to the nature of the impacts, since they tend to affect the environment with or without measures at approximately the same level.

Table 4.2.2.4: Percentages of consequence reduction for each impact individually after the implementation of measures, *(Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

Impact		**Consequence (no measures)**	**Consequence (with measures)**	**Consequence reduction (%)**
Biodiversity	Mean	2.1818	1.9091	-12.5%
	N	11	11	
	Std. Deviation	1.32802	1.37510	
Biodiversity (major accidental spills)	Mean	5.0000	5.0000	0.0%
	N	1	1	
	Std. Deviation	.	.	
Biodiversity (minor accidental spills)	Mean	4.0000	4.0000	0.0%
	N	1	1	
	Std. Deviation	.	.	
Groundwater contamination	Mean	3.1053	2.9474	-5.1%
	N	19	19	
	Std. Deviation	.56713	.77986	
Groundwater contamination (minor accidental spills)	Mean	4.0000	4.0000	0.0%
	N	1	1	
	Std. Deviation	.	.	
Groundwater contamination (major accidental spills)	Mean	5.0000	5.0000	0.0%
	N	1	1	
	Std. Deviation	.	.	
Land take	Mean	2.0000	1.8750	-6.3%
	N	8	8	
	Std. Deviation	.53452	.64087	
Local air quality and global warming (major accidental spills)	Mean	4.0000	4.0000	0.0%
	N	1	1	
	Std. Deviation	.	.	
Noise	Mean	1.1364	1.0000	-12.0%
	N	22	22	
	Std. Deviation	.35125	.00000	
Releases to air (contribution to global warming)	Mean	1.7037	1.2963	-23.9%
	N	27	27	
	Std. Deviation	.54171	.54171	
Releases to air (local air quality and global warming)	Mean	3.5000	3.0000	-14.3%
	N	2	2	
	Std. Deviation	.70711	1.41421	
Releases to air (local air quality and global warming) (minor accidental spills)	Mean	3.0000	2.0000	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Releases to air (local air quality)	Mean	1.5556	1.3333	-14.3%
	N	27	27	
	Std. Deviation	.64051	.48038	

Seismic	Mean	1.0000	1.0000	0.0%
	N	4	4	
	Std. Deviation	.00000	.00000	
Surface water contamination	Mean	2.6800	2.2800	-14.9%
	N	25	25	
	Std. Deviation	.90000	.84261	
Surface water contamination (major accidental spills)	Mean	5.0000	5.0000	0.0%
	N	1	1	
	Std. Deviation	.	.	
Surface water contamination (minor accidental spills)	Mean	4.0000	4.0000	0.0%
	N	1	1	
	Std. Deviation	.	.	
Traffic	Mean	1.1053	1.0526	-4.8%
	N	19	19	
	Std. Deviation	.31530	.22942	
Visual impact	Mean	1.3333	1.2222	-8.3%
	N	9	9	
	Std. Deviation	.70711	.66667	
Water resource depletion	Mean	1.4286	1.1429	-20.0%
	N	7	7	
	Std. Deviation	.53452	.37796	
Total	Mean	1.9521	1.7234	-11.7%
	N	188	188	
	Std. Deviation	1.05102	1.03318	

In accordance with *Table 4.2.2.4*, even if all measures are taken under consideration, in case of a major or minor accidental spill, the consequence is preserved at the same level. Moreover, the same happens regarding the seismic impact. In other words, the devastation of the environment will be unavoidable in case of an accident. Fortunately, the rest of the impacts present a decrease of the consequence after applying the measures.

Table 4.2.2.5: Percentages of likelihood reduction for each impact individually after the implementation of measures, *(Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

Impact		**Likelihood (no measures)**	**Likelihood (with measures)**	**Likelihood reduction (%)**
Biodiversity	Mean	3.0000	2.0909	-30.3%
	N	11	11	
	Std. Deviation	.44721	.30151	
Biodiversity (major accidental spills)	Mean	3.0000	2.0000	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Biodiversity (minor accidental spills)	Mean	3.0000	2.0000	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Groundwater contamination	Mean	2.7368	1.9474	-28.8%
	N	19	19	
	Std. Deviation	.56195	.22942	
Groundwater contamination (minor accidental spills)	Mean	3.0000	2.0000	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Groundwater contamination (major accidental spills)	Mean	3.0000	2.0000	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Land take	Mean	4.5000	4.0000	-11.1%
	N	8	8	
	Std. Deviation	.53452	.53452	
Local air quality and global warming (major accidental spills)	Mean	3.0000	2.0000	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Noise	Mean	4.0000	3.7727	-5.7%
	N	22	22	
	Std. Deviation	.53452	.42893	
Releases to air (contribution to global warming)	Mean	4.2593	3.9259	-7.8%
	N	27	27	
	Std. Deviation	1.05948	1.38469	
Releases to air (local air quality and global warming)	Mean	3.0000	2.0000	-33.3%
	N	2	2	
	Std. Deviation	.00000	.00000	
Releases to air (local air quality and global warming) (minor accidental spills)	Mean	3.0000	2.0000	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Releases to air (local air quality)	Mean	3.8519	3.1111	-19.2%
	N	27	27	
	Std. Deviation	.71810	.80064	

Seismic	Mean	2.7500	2.5000	-9.1%
	N	4	4	
	Std. Deviation	1.50000	1.00000	
Surface water contamination	Mean	2.9200	2.0400	-30.1%
	N	25	25	
	Std. Deviation	.40000	.20000	
Surface water contamination (major accidental spills)	Mean	3.0000	2.0000	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Surface water contamination (minor accidental spills)	Mean	3.0000	2.0000	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Traffic	Mean	4.2105	3.7368	-11.3%
	N	19	19	
	Std. Deviation	.63060	.56195	
Visual impact	Mean	3.4444	3.4444	0.0%
	N	9	9	
	Std. Deviation	1.13039	1.13039	
Water resource depletion	Mean	3.0000	2.8571	-4.8%
	N	7	7	
	Std. Deviation	1.00000	1.06904	
Total	Mean	3.5851	3.0213	-15.7%
	N	188	188	
	Std. Deviation	.92972	1.08936	

Regarding *Table 4.2.2.5*, when measures are applied the likelihood of provoking an impact is minimized, even in case of a major or minor accidental spill. The only exception is the visual impact, since the implementation of the measures does not cause any difference at the outcome.

Table 4.2.2.6: Percentages of risk reduction for each process individually after the implementation of measures, *(Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

Process		**Risk (no measures)**	**Risk (with measures)**	**Risk reduction (%)**
Abandonment (Monitoring and well integrity)	Mean	5.3	3.5	-33.3%
	N	4	4	
	Std. Deviation	1.5	1.0	
Casing and cementing	Mean	7.8	5.0	-35.9%
	N	5	5	
	Std. Deviation	3.6	1.0	
Construction and installation (Implementation of development plan)	Mean	5.9	4.9	-17.0%
	N	8	8	
	Std. Deviation	3.3	3.0	
Crude oil and gas processing	Mean	8.3	5.3	-36.0%
	N	6	6	
	Std. Deviation	3.6	2.2	
Decommissioning (plugging of the well, equipment removal)	Mean	6.6	4.2	-35.6%
	N	9	9	
	Std. Deviation	1.8	.7	
Development drilling	Mean	7.7	5.9	-23.4%
	N	10	10	
	Std. Deviation	3.5	3.8	
Drill cuttings management	Mean	7.4	4.4	-40.5%
	N	5	5	
	Std. Deviation	3.1	1.7	
Drilling of vertical or deviated wells	Mean	10.2	6.4	-36.8%
	N	16	16	
	Std. Deviation	3.9	2.5	
Enhanced recovery (substance injection)	Mean	5.8	3.9	-32.8%
	N	10	10	
	Std. Deviation	2.9	2.1	
Enhanced recovery (water flooding)	Mean	5.1	3.6	-29.3%
	N	8	8	
	Std. Deviation	2.6	1.9	
General investigation of the area (satellite, aerial survey)	Mean	4.3	4.3	0.0%
	N	3	3	
	Std. Deviation	.6	.6	

Hydrocarbon offtakes	Mean	5.6	3.8	-32.1%
	N	5	5	
	Std. Deviation	2.6	1.1	
Management of produced water from exploratory wells	Mean	5.6	3.6	-35.9%
	N	7	7	
	Std. Deviation	2.3	1.1	
Mobilization and equipment establishment	Mean	4.6	3.8	-17.4%
	N	5	5	
	Std. Deviation	.9	1.1	
More specific investigation (geophysical/seismic survey)	Mean	4.6	3.9	-14.6%
	N	9	9	
	Std. Deviation	.9	.8	
Process treatment systems (produced water)	Mean	5.6	3.6	-35.7%
	N	5.0	5.0	
	Std. Deviation	3.1	1.7	
Rehabilitation (site restoration)	Mean	5.5	3.5	-36.4%
	N	4	4	
	Std. Deviation	1.9	.6	
Rig installation	Mean	5.0	4.3	-15.0%
	N	4	4	
	Std. Deviation	.0	.5	
Site operations (major accidental spillages)	Mean	14.3	9.5	-33.3%
	N	4	4	
	Std. Deviation	1.5	1.0	
Site operations (Minor accidental spillages)	Mean	11.3	7.0	-37.8%
	N	4	4	
	Std. Deviation	1.5	2.0	
Site preparation (site clearing and accessibility)	Mean	5.5	4.6	-15.9%
	N	8	8	
	Std. Deviation	2.0	1.4	
Utility systems (Wastewater and sewage)	Mean	4.8	3.7	-24.1%
	N	6	6	
	Std. Deviation	2.3	1.5	
Waste handling	Mean	5.2	4.0	-22.6%
	N	6	6	
	Std. Deviation	2.0	1.1	
Well commissioning	Mean	5.4	3.7	-31.6%
	N	7	7	
	Std. Deviation	3.0	1.5	
Well completion	Mean	7.8	4.0	-48.7%
	N	5	5	
	Std. Deviation	2.7	1.6	
Well pad construction	Mean	6.0	5.0	-16.7%
	N	8	8	
	Std. Deviation	2.1	1.6	

Well Stabilization	Mean	7.5	5.8	-23.3%
	N	4	4	
	Std. Deviation	3.0	1.7	
Well stimulation (hydraulic fracturing)	Mean	5.2	3.6	-30.8%
	N	10	10	
	Std. Deviation	2.4	1.5	
Well testing	Mean	9.0	6.5	-27.8%
	N	2	2	
	Std. Deviation	1.4	2.1	
Well workover	Mean	6.0	4.0	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Total	Mean	6.6	4.6	-29.9%
	N	188	188	
	Std. Deviation	3.2	2.1	

According to *Table 4.2.2.6*, the process of “well completion” and “drill cuttings management” present the greater risk reduction after applying the measures. In general, if all measures are taken under consideration, the risk can be reduced. However, the percentage of reduction depends every time on the nature of the process, in other words on its difficulty and complicity to be completed.

Table 4.2.2.7: Percentages of consequence reduction for each process individually after the implementation of measures, *(Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

Process		**Consequence (no measures)**	**Consequence (with measures)**	**Consequence reduction (%)**
Abandonment (Monitoring and well integrity)	Mean	2.5000	2.0000	-20.0%
	N	4	4	
	Std. Deviation	.57735	.00000	
Casing and cementing	Mean	2.2000	1.8000	-18.2%
	N	5	5	
	Std. Deviation	1.30384	1.09545	
Construction and installation (Implementation of development plan)	Mean	1.5000	1.3750	-8.3%
	N	8	8	
	Std. Deviation	.75593	.74402	
Crude oil and gas processing	Mean	2.3333	2.0000	-14.3%
	N	6	6	
	Std. Deviation	1.03280	.89443	
Decommissioning (plugging of the well, equipment removal)	Mean	1.8889	1.6667	-11.8%
	N	9	9	
	Std. Deviation	.60093	.70711	
Development drilling	Mean	1.9000	1.7000	-10.5%
	N	10	10	
	Std. Deviation	.87560	.82327	
Drill cuttings management	Mean	2.2000	1.6000	-27.3%
	N	5	5	
	Std. Deviation	1.09545	.89443	
Drilling of vertical or deviated wells	Mean	3.1250	2.8750	-8.0%
	N	16	16	
	Std. Deviation	1.50000	1.58640	
Enhanced recovery (substance injection)	Mean	2.0000	1.6000	-20.0%
	N	10	10	
	Std. Deviation	.66667	.84327	
Enhanced recovery (water flooding)	Mean	1.6250	1.3750	-15.4%
	N	8	8	
	Std. Deviation	.51755	.51755	
General investigation of the area (satellite, aerial survey)	Mean	1.0000	1.0000	0.0%
	N	3	3	
	Std. Deviation	.00000	.00000	
Hydrocarbon offtakes	Mean	1.4000	1.2000	-14.3%
	N	5	5	
	Std. Deviation	.54772	.44721	
Management of produced water from exploratory wells	Mean	2.0000	1.2857	-35.7%
	N	7	7	
	Std. Deviation	1.00000	.48795	
Mobilization and equipment establishment	Mean	1.2000	1.0000	-16.7%
	N	5	5	
	Std. Deviation	.44721	.00000	

More specific investigation (geophysical/seismic survey)	Mean	1.1111	1.1111	0.0%
	N	9	9	
	Std. Deviation	.33333	.33333	
Process treatment systems (produced water)	Mean	1.8000	1.6000	-11.1%
	N	5	5	
	Std. Deviation	1.09545	.89443	
Rehabilitation (site restoration)	Mean	1.5000	1.5000	0.0%
	N	4	4	
	Std. Deviation	.57735	.57735	
Rig installation	Mean	1.0000	1.0000	0.0%
	N	4	4	
	Std. Deviation	.00000	.00000	
Site operations (major accidental spillages)	Mean	4.7500	4.7500	0.0%
	N	4	4	
	Std. Deviation	.50000	.50000	
Site operations (Minor accidental spillages)	Mean	3.7500	3.5000	-6.7%
	N	4	4	
	Std. Deviation	.50000	1.00000	
Site preparation (site clearing and accessibility)	Mean	1.3750	1.3750	0.0%
	N	8	8	
	Std. Deviation	.51755	.51755	
Utility systems (Wastewater and sewage)	Mean	1.5000	1.5000	0.0%
	N	6	6	
	Std. Deviation	.83666	.83666	
Waste handling	Mean	1.5000	1.5000	0.0%
	N	6	6	
	Std. Deviation	.83666	.83666	
Well commissioning	Mean	1.5714	1.4286	-9.1%
	N	7	7	
	Std. Deviation	.78680	.78680	
Well completion	Mean	2.0000	1.4000	-30.0%
	N	5	5	
	Std. Deviation	.70711	.89443	
Well pad construction	Mean	1.6250	1.5000	-7.7%
	N	8	8	
	Std. Deviation	.74402	.75593	
Well Stabilization	Mean	2.2500	2.0000	-11.1%
	N	4	4	
	Std. Deviation	.50000	.81650	
Well stimulation (hydraulic fracturing)	Mean	1.9000	1.6000	-15.8%
	N	10	10	
	Std. Deviation	.56765	.69921	
Well testing	Mean	2.0000	1.5000	-25.0%
	N	2	2	
	Std. Deviation	.00000	.70711	

Well workover	Mean	2.0000	2.0000	0.0%
	N	1	1	
	Std. Deviation	.	.	
Total	Mean	1.9521	1.7234	-11.7%
	N	188	188	
	Std. Deviation	1.05102	1.03318	

According to *Table 4.2.2.7*, the consequence does not present great difference in number after the implementation of the measures. The zero deviation means that every intervention to the environment carries an impact that cannot be erased. On the other hand, there are processes, which intervention is not considered irreversible. In this case scenario, the measures help to the reduction of the consequence, up to 36% for example, as it happens through the process of "management of produced water from exploratory wells".

Table 4.2.2.8: Percentages of likelihood reduction for each process individually after the implementation of measures, *(Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016, own editing).*

Process		**Likelihood (no measures)**	**Likelihood (with measures)**	**Likelihood reduction (%)**
Abandonment (Monitoring and well integrity)	Mean	2.2500	1.7500	-22.2%
	N	4	4	
	Std. Deviation	.95743	.50000	
Casing and cementing	Mean	3.8000	3.4000	-10.5%
	N	5	5	
	Std. Deviation	.83666	1.34164	
Construction and installation (Implementation of development plan)	Mean	3.8750	3.6250	-6.5%
	N	8	8	
	Std. Deviation	.64087	1.06066	
Crude oil and gas processing	Mean	3.6667	2.8333	-22.7%
	N	6	6	
	Std. Deviation	.51640	.75277	
Decommissioning (plugging of the well, equipment removal)	Mean	3.5556	2.8889	-18.8%
	N	9	9	
	Std. Deviation	.52705	1.05409	
Development drilling	Mean	4.2000	3.6000	-14.3%
	N	10	10	
	Std. Deviation	.91894	1.26491	
Drill cuttings management	Mean	3.6000	3.0000	-16.7%
	N	5	5	
	Std. Deviation	1.14018	1.00000	

Drilling of vertical or deviated wells	Mean	3.5625	2.6250	-26.3%
	N	16	16	
	Std. Deviation	.81394	1.02470	
Enhanced recovery (substance injection)	Mean	2.8000	2.5000	-10.7%
	N	10	10	
	Std. Deviation	.91894	.70711	
Enhanced recovery (water flooding)	Mean	3.1250	2.6250	-16.0%
	N	8	8	
	Std. Deviation	1.24642	.74402	
General investigation of the area (satellite, aerial survey)	Mean	4.3333	4.3333	0.0%
	N	3	3	
	Std. Deviation	.57735	.57735	
Hydrocarbon offtakes	Mean	4.0000	3.4000	-15.0%
	N	5	5	
	Std. Deviation	.70711	1.34164	
Management of produced water from exploratory wells	Mean	3.1429	3.0000	-4.5%
	N	7	7	
	Std. Deviation	1.21499	1.29099	
Mobilization and equipment establishment	Mean	4.0000	3.8000	-5.0%
	N	5	5	
	Std. Deviation	.70711	1.09545	
More specific investigation (geophysical/seismic survey)	Mean	4.2222	3.6667	-13.2%
	N	9	9	
	Std. Deviation	.83333	1.00000	
Process treatment systems (produced water)	Mean	3.2000	2.4000	-25.0%
	N	5	5	
	Std. Deviation	.44721	.89443	
Rehabilitation (site restoration)	Mean	3.7500	2.5000	-33.3%
	N	4	4	
	Std. Deviation	.50000	.57735	
Rig installation	Mean	5.0000	4.2500	-15.0%
	N	4	4	
	Std. Deviation	.00000	.50000	
Site operations (major accidental spillages)	Mean	3.0000	2.0000	-33.3%
	N	4	4	
	Std. Deviation	.00000	.00000	
Site operations (Minor accidental spillages)	Mean	3.0000	2.0000	-33.3%
	N	4	4	
	Std. Deviation	.00000	.00000	
Site preparation (site clearing and accessibility)	Mean	4.1250	3.6250	-12.1%
	N	8	8	
	Std. Deviation	.83452	1.06066	
Utility systems (Wastewater and sewage)	Mean	3.3333	2.6667	-20.0%
	N	6	6	
	Std. Deviation	.51640	1.03280	

Waste handling	Mean	3.6667	3.0000	-18.2%
	N	6	6	
	Std. Deviation	.51640	.89443	
Well commissioning	Mean	3.4286	2.8571	-16.7%
	N	7	7	
	Std. Deviation	.97590	1.21499	
Well completion	Mean	4.0000	3.2000	-20.0%
	N	5	5	
	Std. Deviation	1.00000	1.30384	
Well pad construction	Mean	3.8750	3.6250	-6.5%
	N	8	8	
	Std. Deviation	.64087	.91613	
Well Stabilisation	Mean	3.5000	3.2500	-7.1%
	N	4	4	
	Std. Deviation	1.73205	1.50000	
Well stimulation (hydraulic fracturing)	Mean	2.7000	2.3000	-14.8%
	N	10	10	
	Std. Deviation	.67495	.48305	
Well testing	Mean	4.5000	4.5000	0.0%
	N	2	2	
	Std. Deviation	.70711	.70711	
Well workover	Mean	3.0000	2.0000	-33.3%
	N	1	1	
	Std. Deviation	.	.	
Total	Mean	3.5851	3.0213	-15.7%
	N	188	188	
	Std. Deviation	.92972	1.08936	

Finally, in accordance with *Table 4.2.2.8*, the likelihood does not present great difference in number after applying the measures. There are processes, in which the measures help to the reduction of the likelihood, up to 33% for example. But in general there is a slight deviation between the percentages given with the measures and without them.

5. Conclusions

Oil industry, like any other industrial activity, impacts the environment in many different ways, e.g. gas releases to the atmosphere (such as carbon dioxide, methane, nitrogen oxides, etc.), water withdrawals, water and soil contamination, etc. The implementation of mitigation measures can significantly reduce both the likelihood and the consequences of incidents and, consequently, the risk. Nowadays, these measures can be interrelated with productivity improvements. Further, sound environmental performance is also considered to be an important factor impacting corporate image.

Based on the findings of the meta-analysis conducted in the context of this thesis, the following conclusions are drawn:

- In terms of environmental aspects, the highest risk values in all different processes and stages, are found in case of major and minor accidental spills for biodiversity, surface and groundwater resources and local air quality (the latter only in case of major accidents). In the absence of mitigation measures, the risk is characterized as high or very high.
- The most risky stage is Stage 2 (i.e. the average risk score is 7.7 based on the risk values of all processes), followed by Stage 3 (average risk score = 6.5). Overall, in the absence of environmental measures, the risk is characterized as moderate.
- The most risky process is by far the drilling of vertical or deviated wells (average risk score = 10.2), followed by crude oil and gas processing (average risk score = 8.3) and development drilling (average risk score = 7.7). The risk is, therefore, moderate to high if no measures are put in place.
- The implementation of mitigation measures can reduce the estimated risk, on average, by almost 30%. Risk reduction ranges between 9% and 56% when examining the environmental aspects. The same stands, more or less, for the different processes used in the oil industry. By means of mitigation measures, risks fall to acceptable levels. For instance, surface water or groundwater contamination risk from minor accidental spills reduces by 33% (i.e. from 12 to 8) and the risk derived from vertical or deviated wells reduces by almost 37% (i.e. from 10.2 to 6.4). In both cases, the overall risk is characterized as moderate.

In conclusion, onshore activities have a number of impacts upon the environment in every stage but they are of minor risk compared to offshore activities. Serious incidents related to widespread damages may be observed only from exploding pipelines, which occur further downstream of onshore oil production processes. Nevertheless, a carefully designed environmental management plan is deemed to be necessary as it provides the means to reduce the overall impacts attributed to oil activities at acceptable levels and create a cleaner and safer process towards sustainability.

6. References

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APPENDIX

Table 1: Synopsis of environmental hazards and risk level for the first stage in onshore activities *(Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

Processes/ technologies	**Environmental Aspects**	**Risk Characterisation (with** expected management measures in place)			**Risk Characterisation (without** expected management measures in place)		
		Likelihood	**Consequence**	**Risk**	**Likelihood**	**Consequence**	**Risk**
1. Identification of resource (desktop study)							
1.1 Identifying target area for favourable geological conditions and Licensing	Desk based task - no specific risks identified so not considered further.						
2. Surveying							
2.1 General investigation: - Aerial survey of land features e.g. satellite imagery, aircrafts, etc.	• Releases to air (local air quality)	Likely	Slight	4 low	Likely	Slight	4 low
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly Likely	Slight	5 moderate
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
2.2 Geophysical testing/investigatios: - Seismic surveys	• Surface water contamination	Rare	Minor	4 low	Occasional	Minor	5 moderate
	• Releases to air (local air quality)	Likely	Slight	4 low	Highly Likely	Slight	5 moderate
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly Likely	Slight	5 moderate
	• Land take	Likely (short term definite)	Slight	4 low	Likely (short term definite)	Slight	4 low
	• Biodiversity impacts	Rare	Slight	2 low	Occasional	Slight	3 low
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
	• Visual impact	Likely (periodic)	Slight	4 low	Likely (periodic)	Slight	4 low
	• Seismic	Likely	Slight	4 low	Highly Likely	Slight	5 moderate
	• Traffic	Likely	Slight (short term	4 low	Highly likely	Slight (short term	5 moderate

			definite			definite	
2.3 Development of conceptual model	Desk based task - no specific risk identified so not considered further.						
3. Site preparation							
3.1 Baseline surveys (ecology, hydrology, groundwater, community impact, etc.)	Investigative task – no specific risk identified so not considered further						
3.2 Mobilisation of drilling rig and equipment and people to the drill location	• Surface water	Rare	Slight	2 low	Occasion al	Minor	6 moderate
	• Releases to air (local air quality)	Likely	Slight	4 low	Likely	Slight	4 low
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly Likely	Slight	5 moderate
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
	• Traffic	Likely	Slight	4 low	Likely	Slight	4 low
3.3 Site preparation (e.g. site clearing, accessibility, infrastructure, etc.)	• Surface water	Rare	Minor	4 low	Occasion al	Minor	6 moderate
	• Releases to air (local air quality)	Likely	Slight	4 low	Highly likely	Slight	5 moderate
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly Likely	Slight	5 moderate
	• Land take	Likely (short term definite)	Minor	8 moderate	Highly likely	Minor	10 high
	• Visual impact	Likely (periodic)	Slight	4 low	Likely (periodic)	Slight	4 low
	• Biodiversity impacts	Rare	Minor	4 low	Occasion al	Minor	6 moderate
	• Noise	Likely (periodic)	Slight	4 low	Likely (periodic)	Slight	4 low
	• Traffic	Likely (short term definite)	Slight	4 low	Likely (short term definite)	Slight	4 low

Table 2: Synopsis of environmental hazards and risk level for the second stage in onshore activities *(Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

Processes/ technologies	Environmental Aspects	Risk Characterisation (with expected management measures in place)			Risk Characterisation (without expected management measures in place)		
		Likelihood	Consequence	Risk	Likelihood	Consequence	Risk
4. Exploration well construction							
4.1 Well pad construction	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Occasional	Minor	6 Moderate	Likely	Minor	8 moderate
	• Releases to air (local air quality)	Likely	Minor	8 Moderate	Likely	Minor	8 Moderate
	• Releases to air (contribution to global warming)	High Likely	Slight	5 Moderate	High Likely	Slight	5 Moderate
	• Biodiversity impacts	Occasional (short term definite)	Slight	3 low	Occasional (short term definite)	Minor	6 moderate
	• Visual impact	Likely (periodic)	Slight	4 low	Likely (periodic)	Slight	4 low
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
	• Traffic	Likely	Slight	4 low	Likely	Slight	4 low
4.2 Rig installation	• Releases to air (local air quality)	Likely	Slight	4 low	Highly Likely	Slight	5 moderate
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly Likely	Slight	5 moderate
	• Noise	Likely	Slight	4 low	Highly Likely	Slight	5 moderate
	• Traffic	Likely	Slight	4 low	Highly Likely	Slight	5 moderate

4.3 Drilling of vertical or deviated wells	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Moderate	6 Moderate	Occasional	Major	12 high
	• Water resource depletion	Likely	Slight	4 low	Likely	Slight	4 low
	• Releases to air (local air quality)	Occasional	Minor	6 Moderate	Likely	Moderate	12 high
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly likely	Minor	10 high
	• Biodiversity impacts	Rare	Slight	2 low	Likely	Slight	4 low
	• Noise	Likely	Slight	4 low	Highly likely	Slight	5 moderate
	• Traffic	Likely (short term definite)	Slight	4 low	Highly likely	Slight	5 moderate
	• Groundwater contamination *(major accidental spills)*	Rare	Catastrophic	10 high	Occasional	Catastrophic	15very high
	• Surface water contamination *(major accidental spills)*	Rare	Catastrophic	10 high	Occasional	Catastrophic	15very high
	• Releases to air (local air quality and global warming) *(major accidental spills)*	Rare	Major	8 moderate	Occasional	Major	12 high
	• Impact to biodiversity *(major accidental spills)*	Rare	Catastrophic	10 high	occasional	Catastrophic	15 very high

	• Groundwater contamination *(minor accidental spills)*	Rare	Major	8 moderate	occasional	Major	12 high
	• Surface water contamination *(minor accidental spills)*	Rare	Major	8 moderate	occasional	Major	12 high
	• Releases to air (local air quality and global warming) *(minor accidental spills)*	Rare	Minor	4 low	Occasional	Moderate	9 moderate
	• Biodiversity impact *(minor accidental spills)*	Rare	Major	8 moderate	occasional	Major	12 high
4.4 Drill cuttings management	• Groundwater contamination	Rare	Slight	2 low	Rare	Minor	4 low
	• Surface water contamination	Rare	Moderate	6 moderate	Occasional	Major	12 high
	• Releases to air (local air quality)	Occasional	Minor	6 moderate	Likely	Minor	8 moderate
	• Releases to air (contribution to global warming)	Likely	Slight	4 low	Likely	Minor	8 moderate
	• Traffic	Likely (short term definite)	Slight	4 low	Highly likely (short term definite)	Slight	5 moderate
4.5 Casing and cementing	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high

	• Surface water contamination	Rare	Moderate	6 Moderate	Occasional	Major	12 high
	• Releases to air (local air quality)	Likely	Slight	4 low	Likely	Slight	4 low
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly likely	Minor	10 high
	• Water resource depletion	Likely	Slight	4 low	Likely	Slight	4 low
4.6 Well Stabilisation	• Groundwater contamination	Rare	Moderate	6 Moderate	Rare	Moderate	6 Moderate
	• Surface water contamination	Rare	Minor	4 low	Rare	Minor	4 low
	• Releases to air (local air quality)	Likely	Minor	8 Moderate	Highly likely	Minor	10 high
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly likely	Minor	10 high
5. Well testing							
5.1 Well testing	• Releases to air (local air quality)	Likely	Minor	8 Moderate	Likely	Minor	8 Moderate
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly likely	Minor	10 high
5.2 Management of produced water from exploratory wells	• Groundwater contamination	Rare	Minor	4 low	Rare	Moderate	6 moderate
	• Surface water contamination	Rare	Minor	4 low	Rare	Moderate	6 moderate

	• Releases to air (local air quality)	Rare	Slight	2 low	Occasional	Slight	3 low
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly likely	Minor	10 high
	• Biodiversity impacts	Rare	Slight	2 low	Rare	Moderate	6 moderate
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
	• Traffic	Likely	Slight	4 low	Likely	Slight	4 low
5.3 Revised conceptual model and resource estimate	Desk based task - no specific risk identified so not considered further.						
5.4 Assessment	Desk based task - no specific risk identified so not considered further.						
6. Well completion							
6.1 Well completion	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Slight	2 Low	Occasional	Minor	6 moderate
	• Releases to air (local)	Occasional	Slight	3 Low	Highly likely	minor	10 high
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly likely	minor	10 high
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low

Table 3: Synopsis of environmental hazards and risk level for the third stage in onshore activities *(Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

Processes/ technologies	**Environmental Aspects**	**Risk Characterisation (with** expected management measures in place)			**Risk Characterisation (without** expected management measures in place)		
		Likelihood	**Consequence**	**Risk**	**Likelihood**	**Consequence**	**Risk**
7. Field development design							
7.1 Field development: - Field development concept - Front end engineering design - Detailed design	Desk based task - no specific risk identified so not considered further.						
8. Construction and installation							
8.1 Implementation of development plan	• Surface water contamination	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Releases to air (local air quality)	Likely (short term definite)	Slight	4 low	Likely (short term definite)	Slight	4 low
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 Moderate	Highly likely	Minor	10 high
	• Land take	Likely	Moderate (wider scale)	12 High	Likely	Moderate (wider scale)	12 High

	• Biodiversity impacts	Rare	Slight	2 low	Occasional	Slight	3 low
	• Visual impact	Likely (periodic)	Slight	4 low	Likely (periodic)	Slight	4 low
	• Noise	Likely (periodic)	Slight	4 low	Likely (periodic)	Slight	4 low
	• Traffic	Likely (short term definite)	Slight	4 low	Likely (short term definite)	Slight	4 low
9. Hook-up and commissioning							
9.1 Well commissioning - Well hook- up - Pre- commissioning - Commissioning	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Releases to air (local air quality)	Occasional	Slight	3 low	Likely	Slight	4low
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 Moderate	Highly likely	Minor	10 high
	• Water resource depletion	Rare	Slight	2 low	Rare	Slight	2 low
	• Biodiversity impacts	Rare	Slight	2 low	Occasional	Slight	3 low
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
10. Development drilling – if required, once field development in place							
10.1 Development drilling (further development, if required)	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Minor	4 low	Occasional	Moderate	9 high
	• Releases to air (local air quality)	Occasional	Slight	3 low	Likely	Slight	4 low

	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 Moderate	Highly likely	Minor	10 high
	• Water resource depletion	Likely	Slight	4 low	Likely	Slight	4 low
	• Land take	Highly likely	Minor	10 high	Highly likely	Minor	10 high
	• Biodiversity impacts	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Noise	Likely	Slight (Temporary)	4 low	Highly likely	Slight	5 moderate
	• Visual impact	Highly likely	Moderate	15 Very high	Highly likely	Moderate	15 Very high
	• Traffic	Likely	Slight	4 low	Highly likely	Slight	5 moderate
11. Hydrocarbon production – Hydrocarbon production and processing							
11.1 Crude oil & gas processing Operation of plant and process equipment and maintenance activities*	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Minor	4 low	Occasional	Moderate	9 high
	• Releases to air (local air quality)	Occasional (Periodic)	Minor	6 Moderate	Likely (periodic)	Moderate	10 high
	• Releases to air (contribution to global warming)	Occasional (Periodic)	Moderate	9 high	Likely	Moderate	12 high
	• Noise	Occasional	Slight	3 low	Likely	Slight	4 low
	• Traffic	Likely (periodic)	Slight	4 low	Likely (periodic)	Slight	4 low

*For oil, this is a typical three phase separation: oil, gas and water.

11.2 **Site operations** - Major accidental spillages of fluids related to platform operations	• Groundwater contamination	Rare	Catastrophic	10 high	Occasional	Catastrophic	15very high
	• Surface water contamination	Rare	Catastrophic	10 high	Occasional	Catastrophic	15very high
	• Releases to air (local air quality and global warming)	Rare	Major	8 moderate	Occasional	Major	12 high
	• Impact to biodiversity	Rare	Catastrophic	10 high	occasional	Catastrophic	15 very high
11.2 **Site operations** - minor accidental spillages of fluids related to platform operations	• Groundwater contamination	Rare	Major	8 moderate	occasional	Major	12 high
	• Surface water contamination	Rare	Major	8 moderate	occasional	Major	12 high
	• Releases to air (local air quality and global warming)	Rare	Minor	4 low	Occasional	Moderate	9 moderate
	• Impact to biodiversity	Rare	Major	8 moderate	occasional	Major	12 high
11.3 **Well workover** – Conducted during monitoring and maintenance of completed wells.	• Surface water contamination	Rare	Minor	4 low	Occasional	Minor	6 moderate
11.4 **Process treatment systems** – Produced water collection and management	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Minor	4 low	Occasional	Moderate	9 high

	• Releases to air (local air quality)	Rare	Slight	2 low	Occasional	Slight	3 low
	• Releases to air (contribution to global warming)	Rare	Slight	2 low	Occasional	Slight	3 low
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
11.5 Utility systems - Wastewater and sewage collection and treatment	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Releases to air (local air quality)	Rare	Slight	2 low	Occasional	Slight	3 low
	• Releases to air (contribution to global warming)	Rare	Slight	2 low	Occasional	Slight	3 low
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
	• Traffic	Likely	Slight	4 low	Likely	Slight	4 low
11.6 Waste handling - Waste handling, storage, collection and transport	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Releases to air (local air quality)	Occasional	Slight	3 low	Likely	Slight	4 low
	• Releases to air (contribution to global warming)	Occasional	Slight	3 low	Likely	Slight	4 low
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
	• Traffic	Likely	Slight	4 low	Likely	Slight	4 low

11.7 Hydrocarbon offtakes - product export, pipelines / road tankers within the production process boundary.	• Surface water contamination	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Releases to air (local air quality)	Rare	Slight	2 low	Likely	Slight	4 low
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 Moderate	Highly likely	Minor	10 high
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
	• Traffic	Likely	Slight	4 low	Likely	Slight	4 low
11.8 Enhanced recovery (Water flooding) – water injection to sweep field and boost production.	• Releases to air (local air quality)	Slight	Occasional	4 low	Minor	Occasional	6 moderate
	• Releases to air (contribution to global warming)	Minor	Rare	3 low	Minor	Rare	3 low
	• Water resource depletion	Minor	Rare	4 low	Minor	Occasional	6 moderate
	• Land take	Minor	Likely	8 moderate	Minor	Highly Likely	9 high
	• Noise	Slight	Occasional	4 low	Minor	Occasional (short-term definite)	6 moderate
	• Visual impact	Slight	Rare	2 low	Slight	Rare	2 low
	• Seismic (induced seismicity)	Slight	Rare	2 low	Slight	Rare	2 low
	• Traffic	Slight	Occasional	4 low	Slight	Highly likely	5 moderate
11.9 Enhanced recovery (substance injection) – steam / miscible gas / polymer injection	• Groundwater contamination	Moderate	Rare	6 moderate	Moderate	Occasional	9 high
	• Surface water contamination	Moderate	Rare	6 moderate	Moderate	Occasional	9 high

	• Releases to air (local air quality)	Slight	Occasional	4 low	Minor	Occasional	6 moderate
	• Releases to air (contribution to global warming)	Minor	Rare	3 low	Minor	Rare	3 low
	• Water resource depletion	Slight	Rare	2 low	Minor	Rare	4 low
	• Land take	Minor	Likely	8 moderate	Minor	highly likely	9 high
	• Noise	Slight	Occasional	4 low	Minor	Occasional (short-term definite)	6 moderate
	• Visual impact	Slight	rare	2 low	Slight	rare	2 low
	• Seismic (induced seismicity)	Slight	Rare	2 low	Slight	Rare	2 low
	• Traffic	Slight	Occasional	4 low	Minor	Occasional	6 moderate
11.10 Well stimulation (low volume hydraulic fracturing) – fracturing to release gas and/or oil.	• Groundwater contamination	Moderate	Rare	6 moderate	Moderate	Occasional	9 high
	• Surface water contamination	Minor	Rare	4 low	Minor	Occasional	6 moderate
	• Releases to air (local air quality)	Slight	Occasional	4 low	Minor	Occasional	6 moderate
	• Releases to air (contribution to global warming)	Minor	Rare	3 low	Minor	Rare	3 low
	• Water resource depletion	Slight	Rare	2 low	Minor	Rare	4 low
	• Land take	Minor	Occasional	6 moderate	Minor	Likely	8 moderate

	• Noise	Slight	Occasional	4 low	Minor	Occasional (short-term definite)	6 moderate
	• Visual impact	Slight	Rare	2 Low	Slight	Rare	2 Low
	• Seismic (induced seismicity)	Slight	Rare	2 Low	Slight	Rare	2 Low
	• Traffic	Minor	Rare	4 low	Minor	Occasional	6 moderate

Table 4: Synopsis of environmental hazards and risk level for the fourth stage in onshore activities *(Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

Processes/ technologies	**Environmental Aspects**	**Risk Characterisation** (**with** expected management measures in place)			**Risk Characterisation** (**without** expected management measures in place)		
		Likelihood	**Consequence**	**Risk**	**Likelihood**	**Consequence**	**Risk**
12. Decommissioning and rehabilitation planning							
Project cessation, well closure and decommissioning	Planning the deployment of decommissioning task - no specific risk identified so not considered further.						
13. Decommissioning of equipment and reclamation							
13.1 Decommissioning - Plugging of wells, removal of well pads and waste management	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Releases to air (local air quality)	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Releases to air (contribute • on to global warming)	Rare	Minor	4 low	Likely	Minor	8 moderate
	• Land take	Likely	Slight	4 low	Likely	Minor	8 moderate
	• Visual impact	Likely	Slight	4 low	Likely	Minor	8 moderate
	• Biodiversity impacts	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
	• Traffic	Likely	Slight	4 low	Likely	Slight	4 low
14. Rehabilitation							
14.1 Site restoration	• Noise	Occasional	Slight	3 Low	Likely	Slight	4 low
	• Traffic	Occasional	Slight	3 Low	Likely	Slight	4 low
	• Releases to air (local air quality)	Rare	Minor	4 low	Occasional	Minor	6 moderate

	• Releases to air (contribution to global warming)	Rare	Minor	4 low	Likely	Minor	8 moderate

Table 5: Synopsis of environmental hazards and risk level for the fifth stage in onshore activities *(Source: Amec Foster Wheeler Environment & Infrastructure UK Ltd, 2016).*

Processes/ technologies	**Environmental Aspects**	**Risk characterisation** (**with** expected management measures in place)			**Risk characterisation** (**without** expected management measures in place)		
		Likelihood	**Consequence**	**Risk**	**Likelihood**	**Consequence**	**Risk**
15. Post closure and abandonment							
15.1 Long- term well integrity and monitoring	Groundwater contamination	Extremely Rare	Minor	2 low	Extremely Rare	Moderate	4 low
	Surface water contamination	Rare	Minor	4 low	Rare	Moderate	6 moderate
	Releases to air (contribution to global warming)	Rare	Minor	4 low	Occasional	Minor	6 moderate
15.2 Relinquishing licences	Project completion - no significant risk associated with this activity, therefore it is not considered further.						